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ORIGINAL ARTICLES.

The Petrology of some Yorkshire Boulder Clays.

By Dr. A. Raistrick, M.Sc., F.G.S.

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ONE of the most imposing and best known exposures of glacial deposits in the north of England is the line of high cliffs along the Yorkshire coast, between Patrington and Withernsea, the highest point of the cliffs being at Dimlington Beacon. Here 140 feet of glacial material is exposed in the cliff face and the foreshore is entirely of boulder clay, the base of the deposits being a long way below sea-level. The work of this paper relates to the clays and sands in this cliff exposure. The deposits are easily distinguished as being of three varieties; at the base and along the foreshore, a dark leaden grey to black, tough boulder clay, including lenticles of sand frequently containing shell fragments; this is succeeded by a thick clay of rich purple or red colour, with noticeably more contained boulders, and near the top, much included sand in lenticles, passing into a bed of pure sand; the highest part of the cliff is of earthy clay, foxy red in colour, and with relatively few boulders. These are respectively the Basement clay, the Purple clay, and the Hessle clay. Between the Basement clay and the Purple, and at the top of the Purple clay, there are beds of sand a few feet thick; these are not to be seen at all parts of the coast, but are generally present in the highest sections. Fig. 1 is a vertical section of the Dimlington cliff, and the Roman numerals indicate the specimens petrologically examined.

The exposed part of the Basement clay is about 20 ft. thick, of which the greater part is the leaden grey "upper" division, the darker "lower" Basement clay being seen in the foreshore and occasionally in the base of the cliff. The clay extends to great depths below sea-level, as proved by several bore holes in various parts of Holderness, the Chalk floor being reached at more than 100 feet below O.D. near Dimlington.

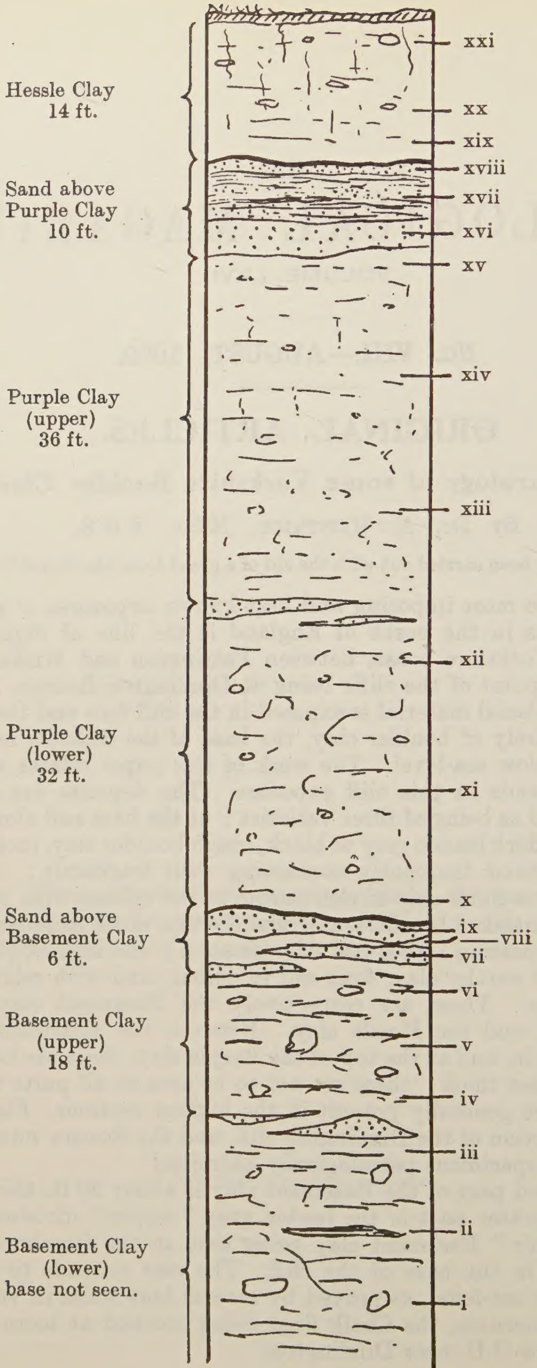

Fig. 1.—Section of Cliff at Dimlington, Yorkshire.

The Lower Basement Clay is very tough, unstratified, and having a fair quantity of included boulders, with occasional masses of sea-bottom material with shells, and also large erratics of Jurassic and Cretaceous rocks. The boulders are chiefly shore pebbles, well rounded, and small boulders of Scandinavian rocks—augite-syenite, rhomb-porphyry, and coarse granites and basalts. At the junction of this lower clay with the upper there are frequent lenticles of sand and fine gravel, from which the material of specimen (iii) was collected, (i) and (ii) being from the clay below this. The upper part of the Basement clay is lighter in colour, of fairly uniform thickness, about 18 ft., and carries a greater variety of boulders, both Scandinavian and British. The Scandinavian boulders are the same species as before, but are usually larger, while the British rocks include small boulders of the Shap granite and distinctive Lake District rocks, with abundant Carboniferous rocks from the Pennines. The Scandinavian rocks are still the distinguishing feature of this clay. Specimens (iv) to (vi) are of this clay.

At the top of the Basement beds is a sharp line of division emphasized by a variable band of yellow sand, occasionally slightly banded, followed by the great mass of the Purple clay, here about 70 ft. thick. Specimens (vii) to (ix) are from this sand. The Purple clay is very tough, bright coloured, and very fine textured, with abundant boulders usually much less in size than those of the Basement clay. The boulders are principally Carboniferous rocks, with Shap granite, Whin Sill, and occasional Magnesian Limestone, while Scandinavian rocks, though not absent, are very rare and very small. There are irregular bands of sand about the middle of the Purple clay, but this work has shown that no real distinction can be made between the lower and upper parts of the Purple clay.

At the top the Purple clay becomes very silty and thin beds of laminated clay and sand to nearly 10 ft. thick become prominent. This bed is important as the source of much of the water of the wells near the coast, and is marked in the cliff by a line of springs. The Hessle clay, above these sands, is markedly different in character from the lower clays, being far more earthy, less dense, and deeply fissured. It is fairly constant in thickness, about 15 ft., and follows the contours of the surface of the Purple clay. It contains abundant boulders, mostly small, and chiefly of Scottish origin, Cheviot and Tweed igneous rocks, and Silurian grauwacke.

The whole of the material collected, 21 specimens from this section and about 50 from various other exposures, chiefly inland, were examined for heavy minerals. The clays were pared into thin slices, which after slow drying in the air, crumbled easily with a rubber-tipped pestle, and could be sieved without difficulty, to get rid of the small pebbles of rock. The material thus obtained was cleared of silt, either by washing in continual changes of water or by elutriating, and in each case a quantity of fine sand obtained, which was very rich in heavy minerals. These were separated out by using Thoulets' solution sp.g. 2·8, and all the minerals obtained mounted on slides for microscopic examination. The preliminary examination of the slides showed that there were two sets of distinguishing features between the clays: first, the actual mineral species present were different in abundance in different clays, secondly the minerals from different clays were strikingly different in size and degree of rounding of the grains. In the Basement clays and sand, the minerals are in large irregular lumps, some fractured and angular, some rounded, with only very rarely any crystal form to be determined. In the Purple clay, the minerals are all small, often perfect in crystalline form, particularly the zircon, and beautifully bright and clear. In the Hessle clay, small, good crystalline minerals reminiscent of the Purple mingle

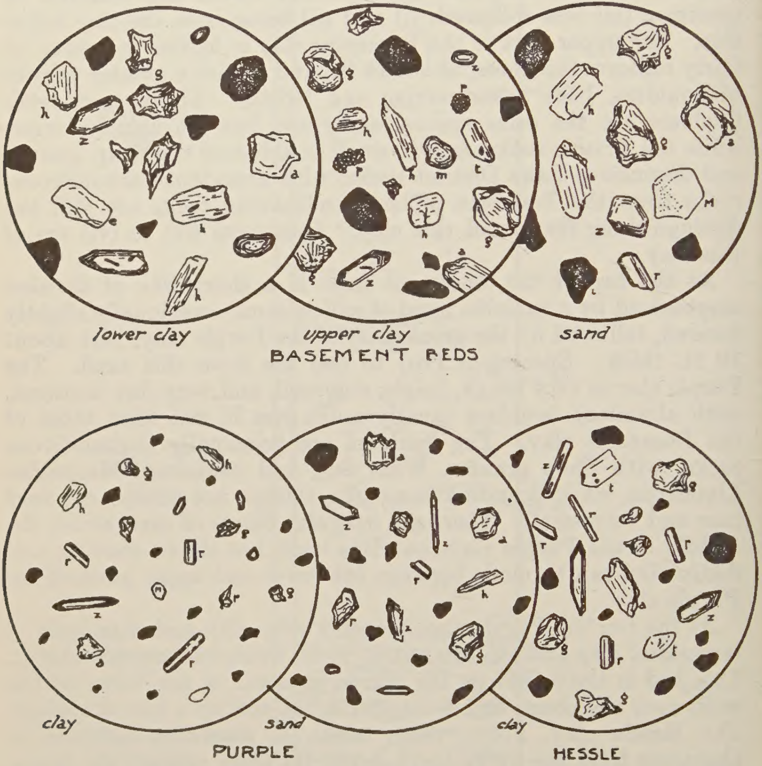

Fig. 2.—Comparative size of minerals in different clays: g, garnet; h, hornblende; a, augite; e, epidote; p, pyrite; M, muscovite; z, zircon; i, ilmenite; t, tourmaline; m, monazite; r, rutile.

with larger broken and rounded fragments, approaching in size and condition the minerals of the Basement clays. These differences of size are illustrated in Fig. 2 where all the minerals are drawn to the same scale of magnification. This variety in size holds good over all the exposures where these clays have been examined and seems to be a specific feature of the deposits. The proportions in which the various minerals are present in each clay will be dealt with later.

As shown in Fig. 1, twenty-one specimens were examined from the section at Dimlington, and the heavy minerals separated from them. The results of this examination are tabulated below. In order to indicate the relative abundance of different minerals the following conventional numbers have been used.

8. Very abundant.
7. Abundant.
6. Very common.
5. Common.
4. Scarce.
3. Very scarce.
2. Rare.
1. Very rare.

	i–iii.	iv–vi.	vii–ix.	x–xii.	xiii–xv.	xvi–xviii.	xix–xxi.
Garnet .	8	8	8	8	8	8	8
Zircon .	5	4	4	7	7	8	8
Tourmaline .	1	1	2	1	1	4	5
Hornblende .	6	6	6	3	1	5	5
Epidote .	2	1	3	2	–	1	3
Rutile .	1	–	1	5	5	7	8
Biotite .	1	1	1	–	1	1	1
Augite .	4	3	4	6	5	6	4
Muscovite .	1	–	1	–	2	1	–
Magnetite .	2	2	2	1	2	2	1
Ilmenite .	6	6	8	7	4	4	5
Pyrite .	2	5	1	–	5	1	2
Marcasite .	–	4	3	3	–	–	–
Andalusite .	1	2	3	–	2	2	–
Hypersthene .	2	2	2	1	1	–	–
Staurolite .	1	1	–	–	2	2	2
Leucoxene .	2	3	–	–	1	–	1
Monazite .	1	1	2	1	–	–	–
Glaucophane .	1	–	1	–	–	–	–
Haematite .	3	4	5	3	1	1	–
	BASEMENT CLAYS.			PURPLE CLAY.			HESSLE.

From this table it will be seen that of the various minerals present in the clays and sands a few may be selected as showing the difference between the various divisions more clearly than the rest. Of these, zircon, hornblende, rutile, augite, and hypersthene are the most useful.

ZIRCON.—This verges between common and scarce in the Lower and Upper Basement clays and the sand above the Basement clay. In the Purple clays and sand it becomes abundant, and in the Hessle clay very abundant. In the Basement beds the zircons are of large size, usually well rounded, sharp crystals being rare and stumpy rounded crystals common. In the Purple clays, long needle crystals, very well formed, and with sharp cut faces, are common, while minute crystals and rounded fragments are very common. None of the zircons attain a size comparable with those of the Basement clays. In the Hessle clay, zircons similar to those of the Purple are common, accompanied by numerous larger, very good crystals. Rounded zircons are less common.

HORNBLENDE.—This is the predominant mineral of the Basement group, being the largest mineral present and by its green and brown colours giving a characteristic sparkle and colour to separations from these clays. The crystals are usually large, somewhat angular, well cleaved, and of various colours between bright green and yellowy-brown. In the Purple group hornblende is very scarce, only occurring in small splinters, or small rounded fragments. In the Hessle clay, hornblende is again common, though the crystals are smaller and more rounded than in the Basement clay.

RUTILE.—This is very rare indeed in the Basement group, only one or two crystals being seen in the nine slides. These crystals are broken but not rounded. In the Purple group good prismatic crystals are very common, and angular fragments usually of very deep colour occur. In the Hessle clay, rutile is very abundant, perfect prismatic crystals and large angular fragments being both very common.

AUGITE.—Though augite is present in the Basement beds, it never becomes more than scarce ; the crystals are large, clear, and sharply angular. In the Purple clays augite is very common, but in smaller fragments than in Basement, while in the Hessle clay it is again rather scarce.

HYPERSTHENE.—This is present in the Basement clays and sand, though rare, and becomes very rare in the Purple and absent in the Hessle clays.

The striking differences are the relative abundance of zircon, rutile, and augite in the Purple and Hessle clays and of hornblende, ilmenite, and hypersthene in the Basement clays, along with the marked difference in size of the mineral fragments, those of the Basement being by far the largest, the Purple the smallest, and the Hessle the intermediate size.

These differences accord to some extent with the origin of the clays ; the Basement, being derived from ice of Scandinavian origin, has drawn its materials from igneous rocks mostly of a very coarse texture (as indicated by the erratic boulders examined from this clay). This has resulted in the included mineral fragments, even after the attrition of the long journey from their place of origin, being still of large size. The Purple clays, derived chiefly from the rocks of the Pennine range, obtain most of the included minerals from the grits of the Carboniferous, Permian, and later formations, in which the minerals are secondary, having already suffered attrition in the formation of the grits, or from the small extent of igneous rocks exposed in the Pennines, the

Whin Sill, or from the Shap granite mass. The abundance of zircon in the Carboniferous grits will amply explain their abundance in the Purple clay.

The Hessle clay, derived from a more northerly source than the Purple, and containing numerous boulders of the Scottish rocks, the Cheviot andesites, and the very large suite of igneous rocks of south Scotland, yields a proportionately richer group of minerals.

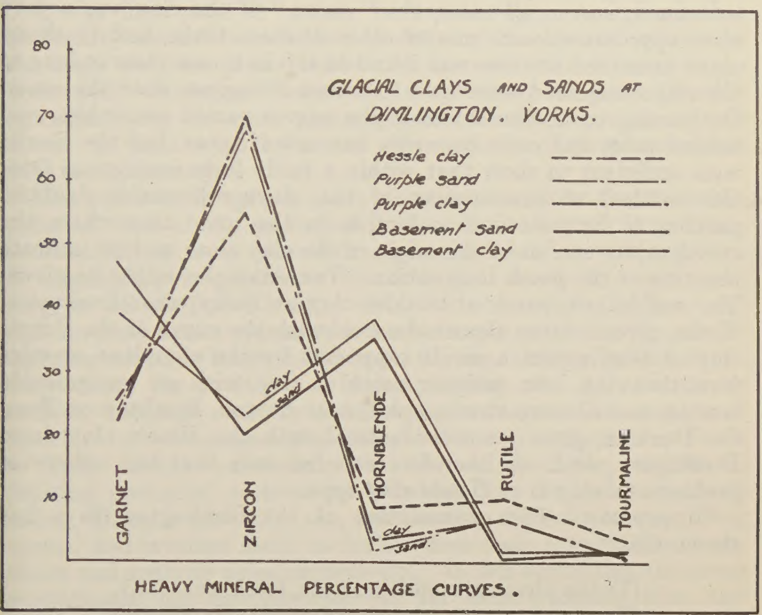

Fig. 3.

Tourmaline is the most noticeable new mineral to appear in quantity, while rutile and zircon are very abundant. The short distance of travel, and the fact that many of the minerals have been derived directly from the igneous rocks in which they are primary minerals, accounts for the general larger size and fresher appearance when compared with those of the Purple clays.

In order to express in visual form the chief differences of the mineral assemblage in the different clays and sands, a percentage curve of five principal minerals has been prepared. A number of areas on the mineral slides, with a perfectly average group of minerals present, were chosen, and all the mineral fragments present were counted and listed by species, until about 1,500 had been counted for each division of the beds. The minerals garnet, zircon, hornblende, rutile, and tourmaline were then selected, and the number of each present in each division expressed as a percentage of the total of all five present in that division. These percentages are then plotted as a curve, the ordinates being percentages, the abscissae being the mineral species. The curves at once show that the clays with the sands above them fall into three groups easily distinguished. The Basement clay and sand, the Purple clay and sand, and the Hessle clay. (See Fig. 3).

Several specimens of boulder clay from inland sections were examined, and in all cases, the " curve " of the clay was a very close approximation to one or other of these three, and in thirty clays examined not one was found to fall in a new class so long as the clays examined were from the coast or regions near the coast. On passing on to the Pennines the curves varied somewhat, and tended more and more toward a new set of types, but the results were sufficient to show that within a fairly large contiguous area, this method of examination of the clays will enable doubtful patches to be related to a section in the same area where the stratigraphy can make the origin of the clay clear and so indicate the date of the patch in question. Two examples might be given. The well-known patch of boulder clay at Balby, near Doncaster, Yorks, gives a curve almost identical with the curve of the Purple clay of Dimlington, a result supported by the abundant erratics from that clay. An outlying patch of clay, with no recognizable erratics and obscure stratigraphy, near Norton, Stockton-on-Tees, Co. Durham, gives a curve identical with the Hessle clay from Dimlington, and one therefore can feel sure that this otherwise problematic clay is of Hessle clay type.

Conclusion.—The examination of the Dimlington clays has shown that

(1) the physical condition (size, freshness, etc.),
(2) abundance or scarcity of particular minerals,
(3) the general mineral assemblage,

in the heavy minerals of the clays are specific characters of each clay and are closely related with the petrology of the area from which the clay has been derived. It also suggests that the sands which occur at the top of the Basement clay and the Purple clay, on the coast, are definitely connected in each case with the underlying clay, and are probably in some measure the result of the denudation of that clay, in the interglacial periods. The nature of the mineral content of the Hessle clay throws doubt on the suggestion frequently made that this clay is the result of weathering and resortment of the underlying Purple clay, and strengthens the idea that it is of distinct origin.

On the Classification of Faults.

By Kenneth W. Earle, D.Sc., F.G.S.

THE experience of several years' teaching in the interpretation of geological maps has convinced the writer of the need for some more satisfactory method of classifying faults than has hitherto obtained.

In the first place it cannot be too strongly emphasized that uniformity should be achieved in defining the *hade* of a fault as the angle the fault plane makes with the vertical and not with the horizontal. Professor Watts, while emphasizing the point himself,[1] immediately in the next paragraph confuses the issue by talking about the *hade* when he means the angle the fault plane makes with the horizontal.

This point being agreed on, it seems to the writer that from the point of view of the geological student far too much importance is attached in most text-books to normal and reversed faults. It is generally impossible in the field, and also from a geological map, to tell whether a fault is normal or reversed, for both normal and reversed faults repeat and cut beds out at the surface under differing relations between the hade, the dip, and the ground slope. Only when the fault has a curved outcrop and its relation to surface contours can be studied on a large scale map is it possible to determine the hade with any accuracy. There is thus always uncertainty in the mind of the student in drawing geological sections as to which way to make the fault hade. There is generally, too, considerable difficulty in visualizing normal and reversed faults as faults which hade towards the downthrow and upthrow sides respectively. In this connection the terms *gravitational* and *compressional* are far more valuable than any definition involving the hade or dip.

The importance of normal and reversed faults is, in fact, chiefly the concern of the miner, as indicating whether a duplication of any stratum will be found in a vertical borehole, or whether *barren ground* will be encountered[2]; and this point should always be stressed in any discussion on normal and reversed faults.

Further, it is not generally emphasized in text-books that normal and reversed faults need not be confined to faults in the direction of strike, but may equally well occur in the direction of dip (Fig. 1).

For the reasons stated above, the writer considers the terms *normal* and *reversed* as of only minor classificatory importance. The primary division of faults into *gravitational* or *tensional* and *compressional* or *tangential* is unsatisfactory in that compressional and tangential are not synonymous terms and thus it leaves the position of such faults as *tears* uncertain.

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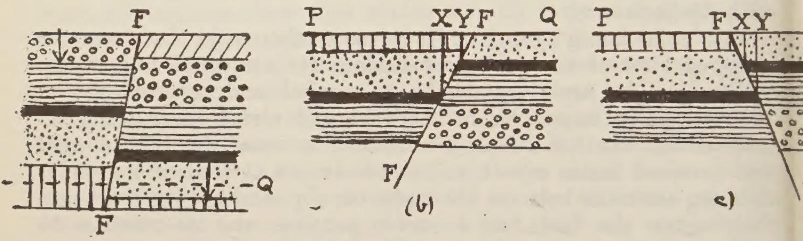
[1] Geol. Mag., 1888, pp. 357, 358.

[2] The student must be warned, however, not to confuse this with repetition or cutting out of beds *at the surface.*

Granting that all classifications are at the best only a compromise and that there are always types which hover between two classes I suggest that the most rational classification of all faults is primarily into three groups: (1) those showing *horizontal* movement along a *vertical* plane; (2) those showing *horizontal* movement along a *horizontal* plane; and (3) those showing *vertical* movement along a *vertical* plane.

The first group is synonymous with the *tear* faults. The effect of these on outcrops, as opposed to ordinary dip faults, is illustrated in most text-books, but it may be noted that tear faults *must* lie in the direction of dip to have any effect on the surface outcrops.



(*a*) FIG. 1.—Normal and Reversed Dip Faults.

(*a*) Plan.
(*b*) Section along *PQ*, if fault be normal, showing barren ground between *X* and *Y*.
(*c*) Section along *PQ* if fault be reversed, showing duplication of stratum between *X* and *Y*.

The second group includes the *thrusts* and *slides*. These may, of course, be considered as strike faults with a very high hade, and all strike faults with a hade greater than 45° can be conveniently classed here. They very seldom lie in the direction of dip.

There seems to be a tendency among some stratigraphical geologists to sometimes allude to faults with nearly vertical fault planes as thrusts. This is to be deprecated, for if they are so named because they show horizontal rather than vertical movement they should be classed as tears.

For the third group of faults—those showing vertical movements along a vertical plane—there seems to be no satisfactory term in general use, and I tentatively suggest the name *slip faults* for want of a better term. These can be sub-divided into dip and strike faults and these again into normal or gravitational and reversed or compressional.

All the particular types, such as step faults, trough faults, etc., will now readily fall into place.

Our complete classification is therefore as follows :—

(1) Faults showing horizontal movement along a vertical plane.
    Tears.

(2) Faults showing horizontal movement along a horizontal plane.
    Thrusts and slides.

(3) Faults showing vertical movement along a vertical plane.
    Slip faults.
  - Dip faults.
    - Normal or gravitational.
    - Reversed or Compressional.
  - Strike faults.
    - Normal or Gravitational.
    - Reversed or Compressional.

On Melilite as a Product of Interaction of Limestone and Basaltic Liquid.

By C. E. Tilley

(with an analysis by Dr. H. F. Harwood).

THE melilite described below is an abundant constituent of a zone of reaction between dolerite and Chalk at the intrusion of Scawt Hill, Co. Antrim, Ireland. The melilite occurs both in the hybrid rock formed by assimilation of carbonate and as a constituent of the exomorphic contact zone. In the latter[1] it is associated with spurrite, Ca_2SiO_4 (larnite), merwinite, spinel, and calcite. The following description applies solely, however, to the melilite of the hybrid rock.

The dolerite of Scawt Hill is a normal ophitic type built up essentially of colourless to pale grey augite and labradorite with less abundant olivine and titaniferous iron ore. The Chalk is almost wholly calcium carbonate with no important accessory constituent.

The product formed as a result of interaction of the limestone and dolerite is a coarsely crystalline dark-coloured rock of which the most abundant constituents are titaniferous augite and melilite. Other constituents varying in amount from place to place are nepheline, aegirine-augite, aegirine, labradorite, wollastonite, perofskite, apatite, iron ores, and a variety of late-formed zeolites and calcite.

In these assemblages melilite is readily recognized by its brown to honey-yellow colour and its vitreous inclining to resinous lustre. It forms crystals up to 1 inch in diameter in association with black titan augite, nepheline, and other constituents.

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[1] Tilley, Geol. Mag., Vol. LXIV, 1927, p. 285.

The habit of the melilite is characteristically tabular on 001. In thin section the crystals show a well-marked basal cleavage. Perofskite is an almost constant companion, often enclosed within its borders. The optical properties have been determined as follows:—

Uniaxial, negative, in thick sections noticeably pleochroic. ω, yellow brown; ϵ, colourless to faint yellow.

The refractive indices determined by the immersion method and on polished plates by the refractometer, are for the central portions of large crystals $\omega_{\mathrm{Na}} = 1{\cdot}647$, $\epsilon_{\mathrm{Na}} = 1{\cdot}636$, $\Delta = 0{\cdot}011$.

The crystals are sometimes more deeply coloured in a narrow border at the periphery, where the pleochroism is stronger and the birefringence increases to ·012–·013.

The interference tints are, however, not noticeably abnormal. In some crystals a patchy variation in birefringence is observable in the interior of crystals and is sometimes located around inclusions of pyroxene or iron ores.

The melilite is slowly decomposed by weak cold HCl with separation of powdery silica.

The large size of the crystals has permitted their easy separation and purification from other constituents, and on material thus purified Dr. H. F. Harwood has kindly executed an analysis (Table I).

TABLE I.

	1	1*a*	1*b*	2	3	
SiO_2 .	37·84	38·35	37·86	40·36	40·14	
Al_2O_3	12·89	13·06	13·17	12·04	6·47	
Fe_2O_3	1·13	1·15	·26	0·75	9·95	Formula A (weight per cent.).
Feo .	5·66	5·74	5·92	1·53	0·53	15 $2CaO.Al_2O_3.SiO_2$.
MgO .	3·12	3·16	3·23	6·56	6·33	22 $2CaO.MgO.2SiO_2$.
CaO .	33·19	33·64	34·29	34·71	32·98	25 $2CaO.FeO.2SiO_2$.
Na_2O	3·93	3·98	4·06	3·34	2·18	23 $3CaO.Al_2O_3.3SiO_2$.
K_2O .	0·25	0·25	0·25	0·30	1·49	4 $3CaO.Fe_2O_3.3SiO_2$.
H_2O+	1·59			0·79	0·27	0·5 $3K_2O.Al_2O_3.3SiO_2$.
H_2O-	0·07			0·13		10·53 $Na_2O.Al_2O_3.3SiO_2$.
TiO_2 .	0·66	0·67			tr.	(15 Ge, 47 Ak, 38 Sa).
	100·33	100·00	99·86	100·51	100·34	

1. Humboldtilite, Scawt Hill, Co. Antrim. Analyst, Dr. H. F. Harwood.
1*a*. Analysis 1, recalculated.
1*b*. Analysis corresponding to Formula A.
2. Humboldtilite, Monte Somma, Vesuvius, A. F. Buddington. *Amer. J. Sci.*, vol. iii, 1922, p. 76.
3. Yellow Melilite, Capo di Bove, *Ibid.*, p. 85.

It is seen from this analysis that the melilite is to be classed with the humboldtilites.[1] The closest chemical analogue is an humboldtilite from Mte. Somma, occurring in pockets of limestone included in leucitite. Computed in terms of the molecules gehlenite, åkermanite, and pseudo-sarcolite, the melilite of Scawt Hill corresponds (see Formula A) quite closely to a solid solution of Ge. 15, Åk.47, Sa.38, ferric oxide being here allotted to the ferric pseudo-sarcolite ($3CaO.Fe_2O_3.3SiO_2$) and ferrous oxide to the ferrous åkermanite ($2CaO.FeO.2SiO_2$). In Fig. 1, the composition of this melilite is graphically plotted together with that of other melilites of igneous rocks in the humboldtilite field.

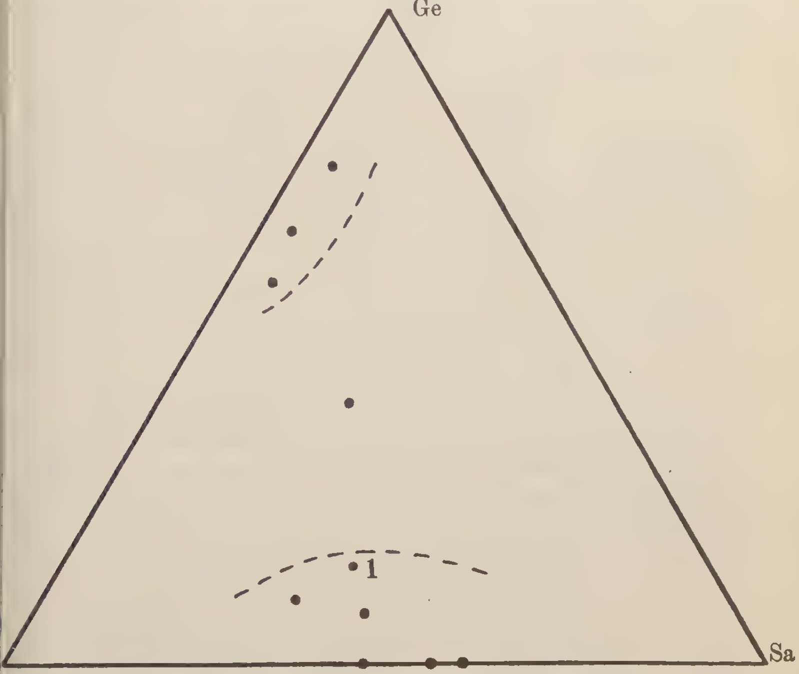

Fig. 1.—Ge = gehlenite. Sa = pseudosarcolite. Ak = åkermanite. 1 = composition of melilite (humboldtilite) of Scawt Hill.

The optical properties of this melilite have revealed it as a variety with an abnormally high birefringence. The only recorded melilites with a comparable birefringence appear to be :—

(*a*) Melilite from a melilite-nepheline-biotite rock (turjaite) from the Kola peninsula recorded by Ramsay[1]: $\omega = 1·631$, $\epsilon = 1·621$, $\Delta = ·010$.

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[1] *I.e.* essentially isomorphous mixtures of åkermanite (including ferrous åkermanite) and pseudo-sarcolite with minor amounts of gehlenite—thus distinct from the melilites rich in ferric iron (such as those of Capo di Bove).

(*b*) Melilite from a melilite-nepheline-pyroxene rock (fasinite) from Tasmania recorded by Erdmannsdörffer and Nieland[2]: $\omega = 1·632$, $\epsilon = 1·623$, $\Delta = ·009$.

(*c*) Melilite from nepheline-melilite rock from Villa Senni near Rome recorded by Washington[3]: $\omega = 1·645$, $\epsilon = 1·63$, $\Delta = ·010$.

Analyses of two melilites, the Turja and Rome occurrences, are available (Table II).

TABLE II.

	4	5
SiO_2 .	41·93	41·68
Al_2O_3 .	8·34	9·86
Fe_2O_3 .	1·54	2·61
FeO . .	3.40	4·32
MgO .	6·26	4·72
CaO . .	31·93	29·85
Na_2O .	4·08	5·27
K_2O . .	0·48	0·78
H_2O + .	1·08	0·98
H_2O — .		—
	99·04	100·07

4. Melilite from turjaite, Turja.
5. Melilite from nepheline melilite rock, Villa Senni.

Buddington, in his investigation of synthetic mixtures of the composition of melilite, has shown that the presence of ferrous iron has the effect of raising both the refringence and the birefringence of the mineral.

This effect is shown for example in the melilites of analyses 1 and 2 (Table I).

	FeO	MgO	ω	ϵ	Δ
1.	5·66	3·12	1·647	1·636	·011
2.	1·53	6·56	1·637	1·631	·006

The same influence is also seen in the less comparable melilite of Table II, the high birefringence of these melilites being due largely to their ferrous oxide content.

It is clear then that the high birefringence of the Scawt Hill melilite is due to its comparatively high content of FeO (computed as 25 per cent. ferrous compound). The analysis, in fact, shows the highest FeO content of any natural melilite yet recorded.

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[1] *Geol. Fören Förh. Stockholm*, vol. xliii, 1921, p. 489.

[2] *Fennia*, vol. l, No. 4, 1928, p. 6.

[3] *Amer. J. Sci.*, vol. xiv, 1927, p. 192.

EFFECTS OF THE ASSIMILATION OF LIMESTONE.

Some parts of the hybrid zone are made up locally of abundant pyroxene with subordinate plagioclase and iron ore.

It is possible that such assemblages represent reaction products in which the incorporated lime has been precipitated in further diopsidic pyroxene by reaction with the $(Mg.Fe)SiO_3$ and Fe_2O_3 molecules present in the constitution of the pyroxene of the dolerite, thus :—

$$FeSiO_3 + MgSiO_3 + Fe_2O_3 + CaO \\ \rightarrow CaMg(SiO_3)_2 + Fe_3O_4$$

The addition of further lime has resulted in the production of the new phase melilite, the origin of which now calls for consideration.

GENESIS OF THE MELILITE.

The meaning of the melilite in the hybrid rock of Scawt Hill is unambiguous. Clearly it arises as a result of an assimilation of calcite by a normal basaltic magma. Fouqué[1] long ago showed that melilite was a product of the fusion of basalt with lime, and similar experiments have been quite recently carried out by Stansfield.[2]

The melilite-bearing rocks of Scawt Hill are, however, remarkable more for the occurrence of alkaline pyroxenes (aegirine-augite and aegirine) and of nepheline. Both alkali pyroxenes and nepheline must also be regarded as products in the chain of reactions.

The occurrence of melilite in rocks of alnöite and polzenite type has been shown by Bowen,[3] on the basis of experimental study, to be perfectly explicable by a reaction proceeding in the liquid between pyroxene and nepheline, producing melilite and an alkaline liquid which appears often as analcime. This method of development for melilite seems to be adequate for the occurrence of most, if not all of the melilite in the alkaline and alnöitic rocks of the Monteregian province of Quebec, and the melilite of the similar rocks of the Polzen district of Bohemia as described by Scheumann.[4] The case is otherwise with the occurrence of melilite in the Scawt Hill hybrid zone. Here the initial invading magma was a dolerite of normal type without any marked alkaline affinities, and the melilite is formed only in the hybrid zone, where nepheline has arisen simultaneously.

The addition of lime to a basaltic liquid may be considered in the light of our knowledge of the equilibrium phenomena of the dry melts of the systems $CaO–MgO–SiO_2$ and $CaO–Al_2O_3–SiO_2$.

The addition of CaO to a melt of the composition of diopside leads to the formation of åkermanite. A melt of the composition of anorthite when similarly treated with CaO, crystallizes as a product

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[1] *Bull. Soc. Min. Fr.*, vol. xxiii, 1900, p. 10.

[2] *Assimilation and Petrogenesis*, 1928, p. 70.

[3] *Amer. J. Sci.*, vol. iii, 1922, p. 1.

[4] (*a*) *Abhandl. Ges. Wiss. Leipzig*, 32, Heft 7, 1912; (*b*) *Centralbl. für Min. . . .* 1922, p. 495.

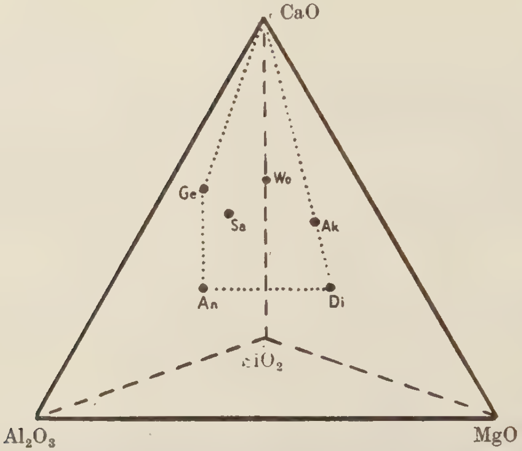

Fig. 2*a*.—Ge = gehlenite. Sa = pseudosarcolite. Wo = wollastonite. Ak = akermanite. Di = diopside. An = anorthite.

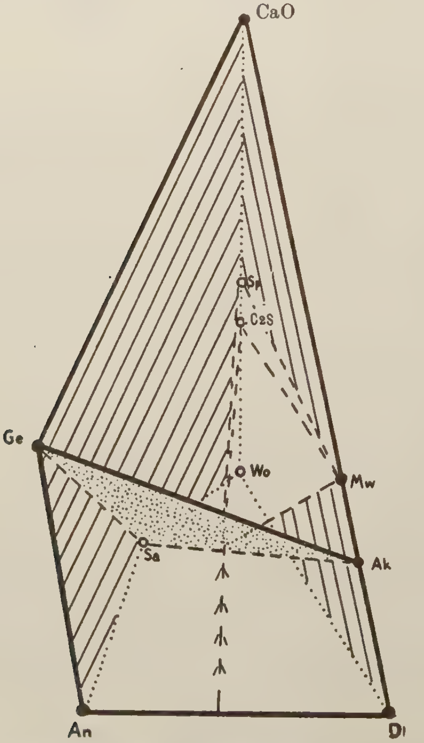

Fig. 2*b*.—Ge = gehlenite. Sa = pseudosarcolite. Ak = akermanite. An = anorthite. Di = diopside. Wo = wollastonite. C_2S = Ca_2SiO_4. Sp = spurrite. Mw = merwinite.

of anorthite, gehlenite, and wollastonite. In the dry melt system $CaO–Al_2O_3–SiO_2$ pseudo-sarcolite is not recorded as a constituent phase, but Buddington has prepared an artificial sarcolite (pseudo-sarcolite) of the composition $3(Ca,Na_2)O.Al_2O_3.3SiO_2$ from a mixture of the appropriate composition. In the presence of soda we might expect to find this molecule appearing as a product of fusion of anorthitic plagioclase with CaO

$$\underset{\text{anorthite}}{2(CaO.Al_2O_3.2SiO_2)} + 3CaO \rightarrow \underset{\text{gehlenite}}{(2CaO.Al_2O_3.SiO_2)} + \underset{\text{pseudo-sarcolite}}{(3CaO.Al_2O_3.3SiO_2)}$$

the soda-sarcolite molecule arising from potential albite in the liquid, excess alumina and silica combining with excess lime to form more pseudo-sarcolite, or gehlenite, and wollastonite.

The composition of the doleritic magma in so far as its molecules of diopside, anorthite, and accessory forsterite are concerned may be graphically represented in the quaternary system within a tetrahedron (Fig. 2*a*) by a point situated close to the join diopside-anorthite in the plane diopside-anorthite-forsterite. It is easy to see that the addition of sufficient lime brings the composition of such a mixture into the field represented by the solid solution series —gehlenite-åkermanite-pseudo-sarcolite, in fact the melilite field. This is represented by the dotted area in Fig. 2*b*, which attempts to visualize that portion of the solid figure bounded by the joins, anorthite-diopside-CaO-gehlenite and the joins CaO-wollastonite$<\begin{array}{l}\text{diopside.}\\ \text{pseudo-sarcolite-anorthite.}\end{array}$ It appears then that melilite is formed in these rocks at the expense largely of anorthite and diopside molecules.

Diopside and the accessory olivine supply the åkermanite molecule while anorthite supplies the pseudo-sarcolite and gehlenite molecules. One of the most interesting features of these rocks is the evidence for the gradual disappearance of plagioclase. The thin sections shows unmistakably that the plagioclase reacts with the liquid and is resorbed. With its disappearance melilite accumulates and nepheline makes its appearance.

Olivine disappears completely and no monticellite is recorded. There results a product rich in alkali pyroxene, melilite and nepheline, with no trace of plagioclase felspar. The story of the production of aegirine and of nepheline by desilication of the residual albite molecule from the labradorite is reserved for another occasion.

The conversion of limestone into lime silicates in solution in igneous magma is undoubtedly a strongly endothermic process. It is in harmony with this fact that we find the zone of hybrid rock is limited and local in its distribution. It is clear, however, that sufficient heat was available to incorporate sufficient carbonate into silicate in solution, to be precipitated as new phases such as melilite, and modify the nature of the residual solutions.

Further Curious Rock-marks from the Cardigan Coast.

By John Challinor, M.A., F.G.S.

ALONG the coast of North Cardiganshire, between Aberystwyth and Borth, numerous rock surfaces bearing "curious marks" have been found during the last few months. One such surface from this region has already been described,[1] but except for a solitary fragment of rock from Transbaikalia [2] this was apparently the only occurrence known anywhere until quite recently. The coast and inland exposures in the neighbourhood of Aberystwyth were explored at the time of the original discovery, but nothing of the same kind was found except a few indefinite traces; however, a more intensive search has now shown that these curiously-marked surfaces are by no means uncommon here.

The general characters of these newly-found surfaces are the same as those of the original surface; that is, they are bedding-surfaces smoothed and striated by fault-movement along them. They are, in fact, the surfaces of "bedding-faults".[3] Also, the general characters of the "marks" are, in the case of each surface, the same as those of the original group and of the "marks" on the Russian specimen.

Among the more interesting of these rock-surfaces is one which forms the steeply-sloping side of a rock situated about 40 yards south-east of the prominent rock (of the nature of a stack), 500 yards north of the Aberystwyth promenade, called the Cormorant Rock (Craig y Filfran). This rock behind the Cormorant Rock is at the foot of the cliff, and is rapidly becoming separated from it by erosion working along the bedding-fault-plane which dips steeply away from the sea and on which the "marks" occur. These "marks" are hooked, and conform to one pattern over a square yard or so. They are not spread continuously, and on different parts of the surface the patterns are different, though they are, as on the surface originally described, no doubt varieties of one "standard" pattern; varieties, that is, in the sense that on one part of the surface one part of the pattern is elaborated, and on another part another. Neighbouring "marks" also vary, though in this case the variation is one of difference in degree of accentuation of the various parts, rather than difference in proportion or difference due to special elaborations or additions. But on this surface, as on others, this variation in degree of accentuation between neighbouring "marks" may be so strong as to give the appearance of there being more than one type of pattern, those "marks" in which one part of the whole pattern is accentuated appearing to conform to one pattern, and those in which another part is accentuated appearing to conform to another different and separate pattern. In some places this surface flakes off and exposes, just below, another surface with quite another type of pattern. This underlying surface is not so polished as the upper. The under surface of the flakes was found to have ridges on it which fitted the grooves below, though these grooves have every appearance of having been formed by the grinding along them of some small projection. In all other cases where it was possible to examine the under-surface of the rock lying immediately above a " marked " surface, there was nothing significant found—no ridges nor small projections—and there was always a very thin layer of clay between the two.

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[1] Geol. Mag., LXIII (1926), pp. 341–3.

[2] Geol. Mag., LXV (1928), pp. 241–4.

[3] Bailey Willis, *Geologic Structures*, pp. 96, 97.

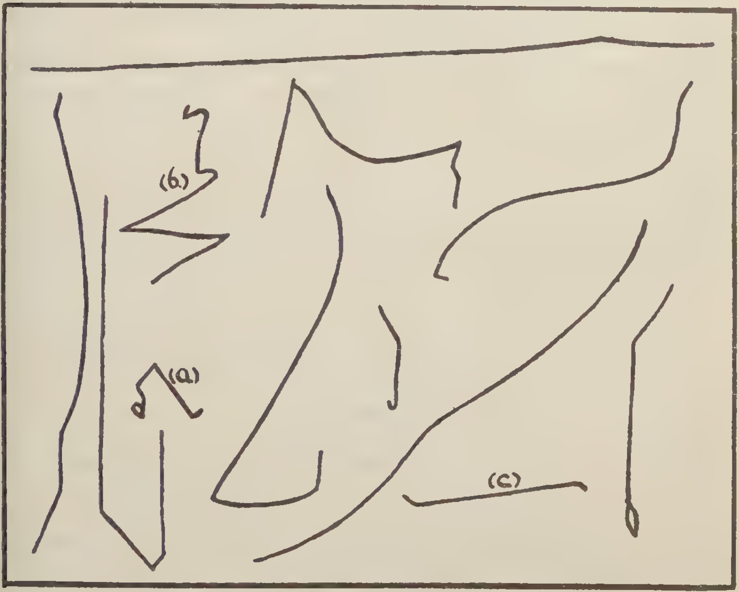


Fig. 1.—Patterns of Rock-marks from the Cardigan Coast.

These patterns figured are selected from the types found along the Cardigan Coast. They are shown in black, but on the surfaces themselves the " marks " are lighter than the background. Each pattern is representative of one surface, and is arranged so that the strike of the surface it represents runs horizontally across the figure. All are drawn natural size. It should be realized that there is great variation in shape from place to place on the larger exposed surfaces, that neighbouring " marks " vary in degree of accentuation of the various parts, and that in any one mark there is variation in width.

(*a*) is the pattern from the original locality, and (*b*) and (*c*) are from the rock behind the Cormorant Rock—(*b*) from the upper, (*c*) from the lower surface.

In the neighbourhood of this rock, other surfaces higher up the cliff amongst the screes show these " marks ", and one in particular is very striking, with large light-coloured hooked streaks crowded together to give a dazzling effect; these are so slightly grooved, however, that a pencil rubbing (a convenient way of recording the "marks" in most cases) shows hardly any sign of them. About 300 yards to the north of this locality is a surface showing two quite distinct sets of "marks"; that is, "marks" which really conform to two types of pattern. This surface thus records two separate movements. Several surfaces with conspicuous "marks" occur just north of Clarach Bay ($1\frac{1}{2}$ miles north of Aberystwyth) and along the coast nearer Wallog (1 mile further on); and between Wallog and Borth particularly well-marked surfaces occur at the foot of the cliff not far from the original locality.

In the original description of this phenomenon it was noted that a graptolite was found on the rock-surface. Some of these new surfaces show graptolites, and on one a small brachiopod has been found. Graptolites are not confined to these particular bedding-surfaces but occur also elsewhere in the mudstone beds; they are, however, rather rare in the Aberystwyth Grits and shelly fossils are exceedingly rare. The chief point of interest in the present connection is that these fossils, found on the bedding-fault-surfaces together with the "curious marks", show no trace whatever of any movement.

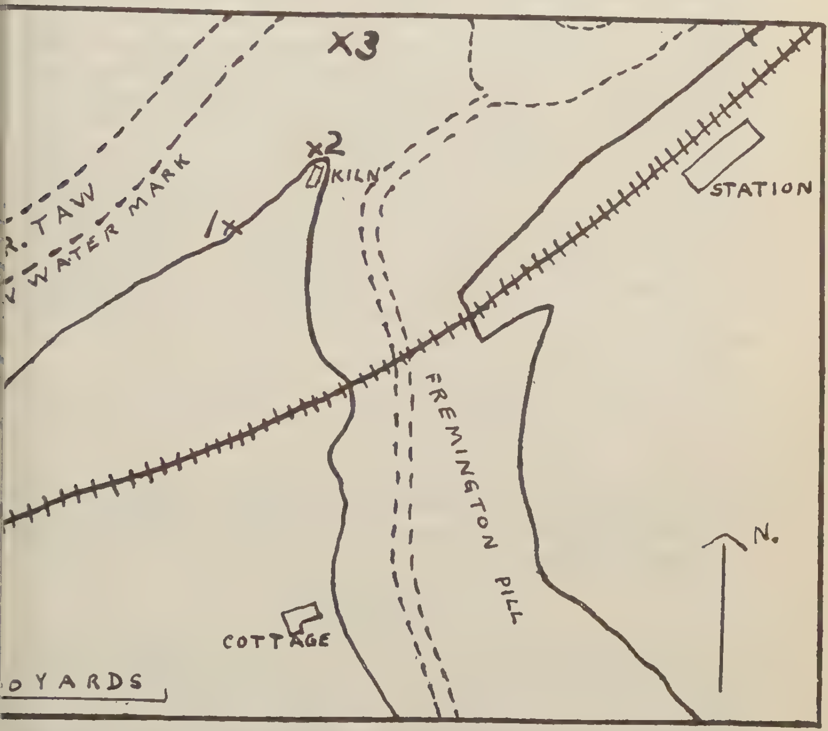
In addition to these new records from the Cardigan Coast, Dr. North informs me of a specimen in the National Museum of Wales. I am greatly obliged to him for allowing me to add to this paper the following note which he sends me:—

"A block of slate with L-shaped scratches, recalling those from Borth, collected by Mr. G. J. Williams, I.S.O., of Bangor, some years ago, is now in the National Museum of Wales. The scratches, which are well-defined, are distributed over one surface, about 8 inches square, of a block of slate from the Narrow Vein (Y Faen fach) of Aberllefenni. The surface on which they occur has a typical mirror-like slickensided appearance, and is in the direction of the bedding of the rock. Mr. Williams records that the scratches were present over the whole of the exposed 'slant', which was probably a fault-plane."

The Occurrence of *Reticuloceras reticulatum* in the Culm of North Devon.

By E. W. J. Moore, B.Sc.

RETICULOCERAS RETICULATUM is the typical goniatite in the topmost beds of the Sabden Shales of Lancashire. This form is known from the Exeter district (Collins and Crick, *Q.J.G.S.*, vol. lxvii, 1911, p. 393), but apparently the only recorded occurrence of this form in North Devon is by Wheelton Hind, who, in the report of a lecture on the correlation of the rocks in North Devon with other areas, is stated to have said, "*Glyphioceras* *reticulatum* has been obtained by Mr. Inkermann Rogers" (*Proc. Geol. Ass.*, vol. xxi, part viii, p. 463). In the summer of 1928, Mr. Rogers was good enough to take the writer over the ground at Ilsey Beach, Lower Yelland, where he had obtained the specimen in question. The beds on this beach contain *Goniatites spiralis* and other goniatites, but not *R. reticulatum.* Inquiries at the British Museum (Natural History) elicited the information that no *R. reticulatum* from Devon was in the Hind Collection. As the specimen cannot be traced, confirmation is impossible. Its identity with *R. reticulatum*, however, is manifestly erroneous, owing to its association with *G. spiralis*, and with the lamellibranch, *Posidonomya becheri*, forms which do not survive to the top of the Bowland Shales of Lancashire.



A small stream called the Pill, enters the River Taw near Fremington Station, and its western bank shows good exposures containing *P. becheri* and some goniatites. These beds dip steeply in a southerly direction, and the presence of *P. becheri* correlates them with the lower part of the Bowland Shales. Near the confluence, the beds are hidden by the railway and by an old limekiln. When the River Taw is reached, a cliff face is seen under the limekiln, and a few feet from the foot of the cliff, just about the level of the high tide, occurs a band of black shale, a few inches thick, containing *R. reticulatum*. *Pterinopecten rythmicus* (Jackson) also occurs here, and these two fossils are associated in the Lancashire beds.

Following the cliff a few yards to the west another band of black shale occurs, and in this is found *R. reticulatum* mut. *α*. The thickness of the beds between the two bands is 75 feet.

Careful searching below the *reticulatum* band yielded no goniatites, but some 70 feet below is a harder band, about 6 inches thick, containing poorly preserved lamellibranchs. Lower in the sequence, approaching the low-tide mark, is a limestone band and shales containing what is apparently *P. becheri*, but the fragmentary nature of the specimens makes specific identification uncertain.

The old records of *R. reticulatum* in the Bowland Shales of Lancashire are now known to be erroneous, and that goniatite is typical of the Sabden Shales much higher in the succession. *Posidonomya becheri*, as is well known, is restricted to the horizon of the Bowland Shales. The presence of the last-named fossil on the west bank of the Pill indicates either that it has a much greater vertical range in Devonshire than in North England or the existence of a fault somewhere along the railway line. In the latter case, the actual junction is not visible.

REFERENCES TO MAP.

1. *Reticuloceras reticulatum* mut. alpha.
2. *R. reticulatum* (type).
3. Lamellibranch band.

Some Characteristic Structural Types in Eastern Asia and their Bearing upon the Problem of Continental Movements.

By J. S. Lee.[1]

I. Introduction.

As a result of wide recognition in recent years of extensive overfolding and overthrusting, it seems to have become generally admitted that continents have actually moved horizontally in times of orogeny; but the problem as to how and to what extent such horizontal movements were effected has continued to be an irritating cause for heated disputes and also a fertile ground for wild speculation. In making the present attempt to attack this controversial problem, it is not intended to deal with the merits or demerits of the several species of theories or hypotheses connected therewith, but simply to direct attention to certain groups of geotectonic phenomena found in Eastern Asia and elsewhere, and also to the mechanism responsible for their production as may be attested by experimental means. In this way it is hoped that mere speculation may be eliminated.

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[1] Professor J. S. Lee, M.Sc., formerly of Peking University, and now Director of the National Research Institute of Geology, Shanghai, is too far away to admit of his personal correction of the proofs of this paper, and he therefore requests me to see it through the press.—W. S. Boulton.

True, Eastern Asia is still poorly known geologically. The doubt is therefore very natural whether some other continental area where the structure is better known may not be a more suitable working base. A survey of our present knowledge as regards the dominant structural features of Eastern Asia, and an inspection of the remarkably well developed structural types in this region, will however soon prove that our choice is not altogether an unfortunate one. In fact we find in this particular region, as will be shown later, characteristic tectonic types that are either undeveloped or obscured in Europe or North America, where our knowledge has reached a far more refined state. Of course every reservation should be made when we come to the discussion of the structural detail of Eastern Asia. Such detailed treatment of the subject is however not the object of the present paper, and is not required for our present purpose. As to the broader features, it may be said that we are in possession of a more or less reliable set of data, particularly in China, Japan and the East Indian Islands. Additional knowledge of further details probably would not materially affect our understanding as to their broader significance.

In view of the fact that Eastern Asiatic structure has often been represented by so-called structural lines since the time of Suess, it may not be out of place to make a few general remarks at the outset on this traditional method. In so far as the structural lines represent the actually observed facts, they are of high synthetic value, and also afford the best material for further analysis. But as soon as the author of a tectonic map begins to link up several disconnected elements by a continuous line—a practice usually resorted to—then personal taste or prejudice become a predominant factor in the resulting map, which may lead to serious error; still more serious is the further step which usually follows; i.e. a more or less arbitrary correlation of the various structural features. This cannot be wholly avoided in the usual practice, because of lack of some basic principle through which the naturally affiliated elements may be appropriately correlated. Thus the completer the map, the more chaotic usually is our knowledge. Harmoniousness and parallelism are often regarded as the key to tectonic interpretation. A little consideration will however show that the first of these terms is altogether too vague to merit a place in scientific literature, and should be for ever abandoned; the second signifies something definite, but it must be realized that parallel structural lines are not always co-genetic, and co-genetic structural elements are certainly not necessarily parallel. Numerous instances of the latter case will appear later.

It would seem then, that given a complete structural plan of

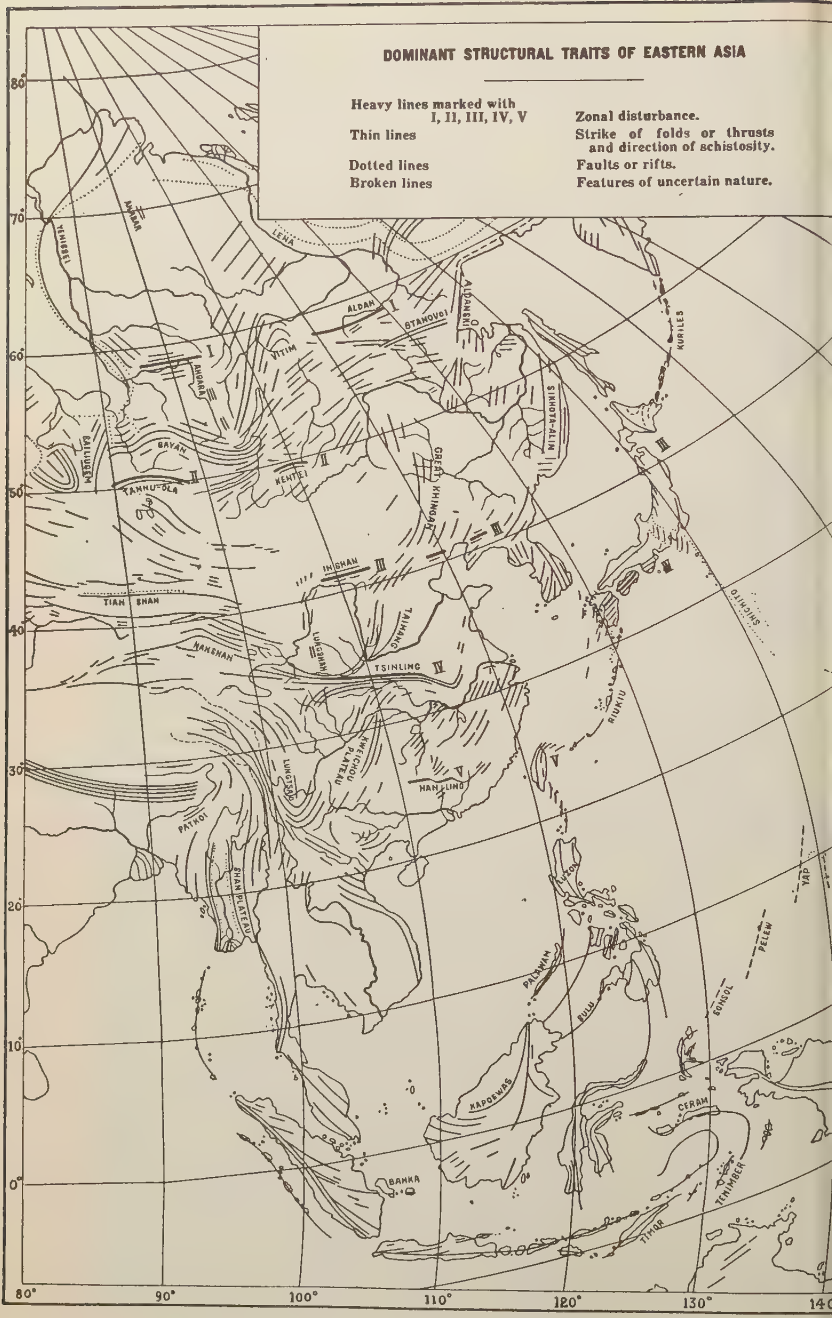

FIG. 1.—A schematic representation of the structural traits of Eastern Asia.

a region, or given a complete tectonic map as constructed by the traditional method, it would still be required to find some sound method for its analysis—a method that should be based upon some definite principle, but not dependent upon the taste or conjecture of the interpreter. We must first of all recognize structural elements through their mechanical meaning; we must also recognize the co-genetic elements as a type. Then comes the question of correlation or co-ordination of the several types occurring in the same region. And lastly we should distinguish the relative order of dominance of the several structural groups which determine the tectonic configuration of an area considered. In following these steps, sufficient attention should be always paid to the genetic process or processes of the different structural groups. The chronological order is of course highly important, but it is not always a determinative factor in such an analysis; for instance, the youngest movement is not always the one that gives rise to the major feature of the region affected.

Starting with these considerations, we may now approach a region selected as our trial base, noting particularly the recurring groups of structural elements therein. If a number of elements be found to associate with each other more than once and always in similar co-ordination, then it is highly probable that we have found a structural type which has been generated by a definite process or set of processes. It is usually possible to deduce, through mechanical considerations, what the processes are; but it would be more satisfactory if we could experimentally produce those features by means of the inferred processes. Assuming that several structural types are thus recognized and established, we then proceed to correlate the processes required to produce those structures. If they be found at variance in the same region, then impotency or fallacy of the experimental deduction is demonstrated. On the other hand, if they are entirely consistent, we should obtain strong evidence, if not absolute proof, of the actual process or processes involved in producing the existing structure. While correlating the several structural groups, the order of dominance of the different groups of features would undoubtedly reveal itself. Finally, if the result thus attained could be extended to other continental areas with equal validity, then we may be confident that we are not far from gaining a glimpse of the truth regarding the fundamental problem of earth-movement.

As may be seen from this abstract scheme, the success or failure of our attempt much depends upon the effective recognition of the types of structural plan. The idea of types of structural plan, or briefly, *structural types*, therefore deserves some emphasis. In the classical method of treatment of geotectonics, we are accustomed to deal with numerous structural features under the terms of various types of folds, faults and thrusts. They are nearly all recognized through a consideration of the elevation of the strata involved.

For a detailed tectonic investigation to a limited horizontal extent, the determination of these features is undoubtedly of paramount importance. But when we come to deal with large tracts like a continent or a section of a continent, a mere understanding of these vertical structural types can no longer afford a sufficient basis by which we can at once recognize the nature of the regional movements. For the latter purpose, it is the structural plan, or more precisely, the characteristic features in the whole plan of the region that will yield more direct information as to the nature of the tectonic movement than the types of the individual fold or fault. To establish this idea, it seems desirable to typify those characteristic plans that are of frequent occurrence and are proved to be the result of a definite genetic process; and further, to name them as we do in distinguishing monocline, isocline, scharnier, Schuppen structure, etc. This proposition marks a new start in tectonic geology. The subject is too vast to be treated systematically in this short paper. What the writer proposes to do here is to select a few types out of the whole plan of Eastern Asia so as to show the nature of such types, and the purpose that they may serve. Terms like *Beugung*, *Scharung*, *Virgation*, *Kettung*, etc., as originally proposed by Suess and more recently redefined by R. Staub,[1] are undoubtedly useful in tectonic, or more particularly, orographic description; but they cannot, nor are they intended to, answer our present purpose.

Before actually entering upon the discussion of the several structural types in Eastern Asia, it is necessary to add some remarks on a few vital points. As has been already said, in distinguishing the structural types, we must constantly pay attention to the mechanical process which generates them. It is a well-known fact that whatever be the original source of the force which promotes tectonic disturbances, the ensuing stresses that are directly responsible for flexuring or fracturing the strata are compression and tension. Compressive stress acting in the horizontal plane produces large and small folds or thrusts; and tensile stress acting horizontally is generally supposed to produce faults or rifts. It is also quite clear that normal faults may be produced through slackening of compression and the operation of gravity. Rifts are without doubt produced through the application of powerful tensile stress.

Inquiring for a moment a little further into details as to how compressive stress may be induced, and what are the principal mechanical results when it operates horizontally in the earth's crust, it is generally believed by geologists that folds with a persistent trend are produced by horizontal pressure normal to their axes. This idea usually degenerates into a remarkable dogma that parallel folds are produced by a crustal movement which originated near or afar along the direction normal to their trend. Being entrenched in this line of thought the geologist completely forgets the fact that it is the normal compressive stress that is responsible for the folding, but not the inferred earth-movement; for compressive stress in a given direction may be induced in a number of different ways. It is true that pressure applied in a given direction can produce compressive stress in the same direction; but it is equally true that compressive and tensile stresses are induced by shear. In this latter case the direction of the compressive stress is not parallel to that of the force which gives rise to the shear; but always oblique to it. This is a well-known principle in elementary mechanics, and is also well shown in our experiments below. From the geotectonic point of view, we can at least distinguish two types of shear; firstly parallel or rectilinear shear, secondly torsional shear. In the first case, the shearing movement, or speaking dynamically, the force that urges the shearing movement, is in a definite direction considered on the horizontal plane; while in the second case, the shearing movement is actually effected around some vertical axis, the result being a torsional movement in the horizontal plane. Each of these produces characteristic types of folds. Here it suffices to say that folds are not always produced by movements normal to their axes.

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[1] Staub, R., *Der Bewegungsmechanismus der Erde*, 1928, pp. 19–21.

There are however certain predominant tectonic features that are always produced by direct pressure with their trend more or less normal to the direction of the force that gives rise to them. These are extensive overfolding or overthrusting, geosynclines and geanticlines. From the mechanical point of view, extensive overfolding and extensive overthrusting may be placed in one and the same category; for they both require a considerable relative movement between the over-riding and the underlying rock-masses. A point of paramount importance in this connection is the actual movement of the masses involved. It is usually assumed by most geologists that the overthrust part is the part that actually moved. This idea has stood so long and has been so firmly held that few seem to have taken the trouble to question its truth. The opposite or rather supplementary idea, namely *underthrusting*, has been rightly emphasized by W. H. Hobbs,[1] and also to some extent developed by H. Stille,[2] E. Argand [3] and L. Kober.[4] The conception of back-folding would be devoid of physical sense unless underthrusting be assumed. At all events if there is reason to believe that an overthrust mass moved in space, there would be just as much reason to believe that the underthrust mass also moved but in the opposite direction. What we really know in connection with

[1] Hobbs, W. H., *Earth Evolution and its Facial Expression*, 1921, pp. 123–34.

[2] Stille, H., *Tektonische Evolutionen und Revolutionen in der Erdrinde*, 1913, pp. 25–6.

[3] Argand, E., "La Tectonique de l'Asie" *C.R. Congrès géol. intern.*, XIIIme session, 1922, pp. 348–53, figs. 13–19.

[4] Kober, L., *Der Bau der Erde*, 1921, pp. 137–76.

thrusting or overfolding is the existence of a zone of powerful compression with its trend more or less normal to the direction of pressure. The factors that determine the overthrust or underthrust side do not necessarily involve the direction of earth-movement. Judging from the history of a number of large geosynclines, the steep side of the original trough appears to be the side that finally turns over. In the case of *plissement à sec*, the part that was originally folded and consequently more or less elevated, seems to be predisposed to ride on the relatively flat land-mass. Whether these generalizations be true or not, is merely a secondary question. The important point is that neither overthrust nor underthrust can be taken as an argument to determine the direction of earth-movement. This becomes palpably plain when we come to consider the tectonic features of the North Sinian massif.

As geosyncline and geanticline are nearly always complementary features, they are probably formed through a single cause. James Hall, who recognized the geosynclinal feature even before James D. Dana to whom the name is due, apparently believed that this kind of earth-trough was caused by subsidence through continued accumulation of sediments. Hall's view is probably correct in so far as it conforms with the modern theory of isostasy. The primary cause of the development of a geosyncline is however undoubtedly to be traced, as was believed by Dana, to lateral compression for at least two obvious reasons: Firstly, the continued growth of geosynclines ends, in the overwhelming majority of cases, in the formation of impressive mountain ranges with extensive thrusting and overfolding. If thrusting and overfolding are to be understood to have resulted from lateral compression, it is only natural to assume that the same kind of force was active throughout its life history. After all, a geosyncline is but a syncline on a grander scale. Secondly, if the geosyncline is formed merely through subsidence, the form of the trough would be a more or less symmetrical one as suggested by E. Haug. In reality however a geosyncline is always of an asymmetrical shape with its steep side close to the " old-land " which is in fact a geanticline, and a gentle slope towards the " marginal plain ". This remarkable property has been carefully determined by A. W. Grabau,[1] and is highly characteristic of a deformative type due to lateral pressure.

These features, produced by direct compression, generally control the configuration of the land-masses or determine the tectonic division of a region. They are therefore *a priori* to be placed in the first order.

Features that are presumably produced by powerful tension appear to have developed on a large scale in the northern part of Eastern Asia, where exploration has unfortunately not yet gone very far. Moreover, they are incapable of reproduction by methods similar to those employed here to produce folds. They are therefore disregarded for the present. But, as we shall see later, those large rifts that are found in East Africa become quite intelligible through the understanding of the mechanism that led to the production of their related folds and thrusts.

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[1] Grabau, A. W., "Migration of Geosynclines," *Bull. Geol. Soc. China*, vol. iii, No. 3–4, 1924, pp. 208–18.

II. METHOD OF EXPERIMENT.

Our method of experiment is extremely simple. The material required consists of a plane and polished board, No. 36 tracing paper supplied by Messrs. Thornton & Co., Ltd., London, a basin of soapy water, and human hands. The pressure or movement required to produce the different types of structure is in all cases supplied by the palm or fingers. The paper is cut to about 8 inches square, and immersed in the soapy water for about five to ten minutes so as to ensure plasticity. The soaked paper is then laid upon the polished board which is already covered with a thin film of water. Care must be taken to avoid the slightest injury to the grain of the paper, and to expel air bubbles locked in the space between the paper and the board. The experimenting material is thus ready for the hand to apply some pressure or movement. More suitable material and a better method [1] can undoubtedly be found; but this is of the readiest kind, and can be easily repeated. One might doubt at the outset the very nature of experiments of this sort. Those who try this method will however soon find that the paper is not so complacent that any feature may be produced at will. After being immersed in water for five to ten minutes, the paper behaves as a plastic, and also to some extent elastic, medium. It responds most readily to shear either rectilinear or torsional. Once it becomes strained, it is almost impossible to induce any unnatural feature by artificial manipulation however skilful. In other words, the induced features are not models such as those made of plaster, but are reactive traits of a thin sheet of an elastico-plastic medium when subjected to definite mechanical processes of disturbance. So long as we are not aiming at anything quantitative, the method seems fully justified.

With so undependable an instrument as the human hand, it is of course not to be expected that a given structural type can always be exactly reproduced. Nevertheless something similar to the expected result is always obtainable provided the disturbing force is rightly applied. In the few typical cases described in this paper, each experiment was repeated several times, and the resulting figures are always essentially like. The question of chance is therefore eliminated.

A curvature of surface such as we actually find on the globe cannot be incorporated in this method of experiment. It undoubtedly plays a part in the actual movement for a given force applied. Its effect may be of some import when a very extensive area on the globe is to be dealt with as a single tectonic unit. In practice, however, the several structural types discussed later are relatively of limited extent. The curvature of the area involved is therefore quite insignificant. Moreover, no apology is needed for the crude nature of our experiment; such refined effect as is due to the curvature of the surface cannot be detected even if a convex board be prepared for the experiment. The very fact that the natural structural types are reproduced on a plane surface through the appropriate application of a disturbing force is itself a proof of the negligibility of the influence of convexity.

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[1] Cf. Mead, J. W., "Notes on the Mechanics of Geologic Structures," *Journ. Geol.*, vol. xxviii, 1920, pp. 505–23.

Some four years ago, the writer made an attempt to demonstrate the genetic relation between the Ural and the great trans-Eurasian Hercynian chain by this method, but nothing more was thought of it until attention was called to more varied attempts made by S. Tokuda.[1] Even then it was not realized that a method of this kind could afford determinative evidence of the mechanism of tectonic movements in general. With the development of the conception of structural types, and the consequent demand for some experimental evidence to confirm the inferred mechanical processes involved in regional movements, the writer has been again led to resort to the once-abandoned method. If this method proves to be of any use, the credit must be attributed to S. Tokuda.

III. The Frame of Eastern Asia.

Tectonically, Eastern Asia may be broadly defined as comprising that part of Asia which is bounded on the west by a line drawn from the south-eastern border of the Taimyr massif southward along the western side of the Yenissei and the western foot of the Sailiugem mountain, further south across the Mongolian Altai, the Gobi desert, the Nanshan ranges, the Tarim basin, still further south passing along the eastern border of the Tibetan massif, then following the north-western border of the Patkoi mountains until the Gulf of Bengal is reached. The eastern boundary is naturally defined by the Pacific. The south-western and southern border is also clearly marked by rows of islands that start with the Andaman-Nicobar group followed by Sumatra, or rather the pre-Sumatra island chain; then comes a powerful sweep towards the east with that remarkable arrangement of the island masses of Java, Flores and Timor.

There is probably not another part of the world that offers the same facility for tectonic study as does Eastern Asia, largely because of its essentially unaltered development in time and its rhythmic variation in space. Recent explorations in eastern Siberia, Mongolia, Turkestan, the Japanese Archipelagoes, China, Indo-China, Burma and the East Indian Islands have greatly augmented our knowledge beside the earlier results of observations summarized by Suess. While it is not the object of the present paper to treat systematically the structural details of the several tectonic regions in this vast territory, it is nevertheless essential to indicate, even though briefly, the more important structural features, so as to be able to appreciate the mechanical meaning of the particular or recurring structural types which are to be singled out as indicators of the mechanism of Eastern Asiatic movements.

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[1] Tokuda, S., "On the Echelon Structure of the Japanese Archipelagoes," *Jap. Journ. Geol. Geogr.*, vol. v, No. 1–2, 1926–7, pp. 41–76.

In defining the areal extent of Eastern Asia, we have tacitly regarded north-eastern Siberia as a part of Eastern Asia. This is natural in the geographical sense. But if we consider it from the tectonic point of view it will be readily seen that that part of the continent which is bounded on the west, south and south-east by the Tchekanovski, Verkhoyanski, Kolymski and Anadyrski mountains stands as a unit of its own. Apart from some early Palaeozoic and late Jurassic folds which run across this boundary and form a divide between the Verkhoyanski and the Kolymski, there are few structural features known within this area that are connected with, or even related to, those outside of this region. Strictly speaking, this part of Asia represents an intermediate land-mass that lies between Asia and the old land Laurentia. Apparently, it has suffered more or less independent movements, at all events, since Mesozoic time. The structure of this region is as yet little known. It would be useless to inquire into the successive movements that it has gone through.

In delineating the predominant tectonic features of the rest of Eastern Asia, the first thing that should be noticed is the existence of *five* zones of powerful disturbance, each of which assumes roughly an east and west trend. Starting from the north, we shall now proceed to make a brief inquiry into the nature of these zones.

The *First Zone* is approximately located in the latitudes of 57° to 58° N. This zone consists of heterogeneous elements, and has been locally subjected to various movements at different times. It is therefore not readily recognizable. Nevertheless we can obtain some notion as to its predominant feature by comparing the structures of the several parts along its length. On the left bank of the Angara, M. Tetjajev[1] observed Archaean schist thrust towards the north over folded continental strata of Jurassic age with an approximately west and east trend. Folding and thrusting with the same strike are apparently repeated both northward and southward to some extent and the whole zone probably stretches from the eastern border of the Yenissei horst eastward to the source of the Lena.

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[1] Tetjajev, M., "Zur Geologie des W. Pribaikalien," *Mat. Geol.*, ii, 1916.

Further east, there appears the Vitim Plateau which is framed by a succession of arcuate folds and thrusts with their convex front facing the north. On the north-western and northern border of this highly compressed old land-mass, the folds are overturned to the north; whereas, in its southern part, the folds are, at first, more or less of a normal type, but as we trace them northward, they become more and more overturned to the south. Thus, considered in the meridional plane, the Vitim Plateau assumes a fan structure. Further complication however arises from the fact that in its north-eastern border the folds strike more or less from north to south and are overturned toward the interior of the massif, that is, to the west or south-west.[1]

Tracing eastward across the Upper Olekma, Tympton and further along the upper and middle Aldan, we find the northern border of the " Ancient Nucleus " (Alter Scheitel) of Siberia stretching from the west to the east in between the latitudes of 57° to 58° N., namely, in about the same latitudinal position as the thrust zone of the Angara district. In his tectonic map of Siberia, W. A. Obrutschev marks the northern border of the Ancient Nucleus with a single line of fracture. Although the exact nature of the fracture is not yet known, there can be little doubt that it has resulted directly or indirectly from meridional pressure; for, from the mouth of the River Siregli eastward, the structural planes of the gneiss which constitutes the northern belt of the Ancient Nucleus, strike persistently to the east with occasional variation to E.S.E. A similar strike is maintained all along the middle course of the Aldan.[2]

It is thus clear that we have a latitudinal zone of disturbance in south-eastern Siberia, which, with the exception of local anomalies, generally assumes a west and east trend. The same view is held by W. A. Obrutschev,[3] a high authority on Siberian geology. A point of importance must however be noted here, that is the fact that this west and east zone apparently terminates on the left side of the Utschur Valley and in the upper course of the Seya. From these points eastward to the coast, the prevailing folds assume entirely different trends. Principally, they are parallel to the axis of the Sikhota-alin, namely N.N.E.

The question as to the date of movement or movements that gave rise to this sinuating latitudinal zone of disturbance is rather difficult to answer. The folds largely traverse the Archaean schist and gneiss, and here and there involve a metamorphic series which Obrutschev considers to be " Eozoic ", but Tetjajev regards them as Lower Cambrian.[4] The latter author postulates an old Palaeozoic geosyncline passing the Olekma-Vitim district and extending north-eastward to the Vilui. This geosynclinal theory proves to be unacceptable to Obrutschev, who maintains that the "Ancient Nucleus" of Siberia was never a part of such a Palaeozoic geosyncline, and that the metamorphic sediments involved are definitely of pre-Cambrian age. Obrutschev further points out the fact that undisturbed Cambrian strata are found to lie flat on the gneiss in the middle course of the Aldan to the north of the northern border of the Ancient Nucleus. It is however also admitted in general terms by the same author that a folded "Eopalaeozoic" formation (? Cambrian) surrounds the border of the Ancient Nucleus. Argand's tentative correlation of the folds of the Olekma-Vitim region with the Caledonian system of folding[1] is likewise rejected by Obrutschev on a similar ground.

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[1] Obrutschev, W. A., *Geologie von Sibirien*, 1926, pp. 49–51, figs. 11, 12.

[2] Sverev, M., " Kurzer Bericht über geol. Forschungen im Tal des Aldan," *Isv. geol. Komit.*, Nr. iv, 1913.

Obrutschev, W. A., *op. cit.*, p. 462.

[4] Tetjajev, M., " Einige Grundfragen der Geologie Sibiriens," *Bull. Soc. Nat. Moscou*, N.S., tome xxxii, No. 3, 1923–4, pp. 155–77.

As a whole, the evidence seems to be strong that the Ancient Nucleus that extends to the east of Transbaikalia was strongly folded and thrust in pre-Cambrian times; but whether similar folding and thrusting were repeated in later dates remains an open question. In the light of our present knowledge it may be granted that this first zone of latitudinal folding and rupture in Eastern Asia assumes a sinuating course to the east of Transbaikalia, and is replaced by N.N.E. folds towards the Maritime Province. It is also important to stress the fact that the zone of the post-Jurassic folding and thrusting in the Angara district follows, within the Amphitheatre of Irkutsk, the same average trend as that which borders the northern boundary of the Ancient Nucleus far to the east.

The *Second Zone* is approximately located between the latitudes of 49° to 50° N. It comprises the Tannu-Ola in its western, and the Kentei in its eastern part, being intercepted in its middle portion by the Khangai Mountains whose structural axes seem largely to follow the Amphitheatre of Irkutsk. This zone forms the natural boundary between Siberia and Mongolia. In the western extension of the Tannu-Ola A. V. Adrianov found mica-schists and fine-grained granite as well as a dark-coloured rock forming the high mountains of the Shap-Shal with their structural planes striking east and west. The same strike was observed by Adrianov in descending the Shap-Shal along the course of a tributary which feeds the Kemtchik from the south.

Some distance to the east of the route followed by Adrianov, several traverses were made by Krylov, Klementz, Potanin and others[2] from the valley of the Ulu-Kem on the north to the Ubsa-Nor on the south. According to these observers, this part of the Tannu-Ola is composed of gneisses, porphyries, granites and conglomerates, sandstones and shales of Devonian and Culm ages. A considerable thickness of the Angara Series sometimes directly overlies the Devonian and the Culm. Volcanic activity is indicated by the presence of tuffs and tuffaceous sandstones. In eastern Tannu, south of the Kha-Kem Valley, the coal-bearing Angara Series seems to have been involved in the formation of the mountain. From the Shap-Shal to the higher reach of the Kha-Kem, the axis of the mountain essentially strikes west and east. Further east the axis appears to have gradually turned to the south-east, so as to conform with the trend of the East Sayan.

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[1] Argand, E., *op. cit.*, pp. 187–8.

[2] Suess, E., *op. cit.*, tome iii, pp. 111–17.

In the Kentei Mountains, the Greywacke Formation which unconformably overlies the Barkhinian Formation, forms a broad fold-arc in its western part with its convex front facing N.N.W., but towards the east its major axis runs E.–W. with variation to E.S.E.[1]

Although the detailed structure of the Tannu-Khangai-Kentei ranges is not yet definitely known, the available information seems to show that the dominant strike of the Tannu and Kentei is essentially west and east, and that the first orogenic movement in this zone probably dated back to some ancient geological time—the end of Devonian or still earlier.

The *Third Zone* is located in the latitudes of 41° to 42° N., and is known to Chinese geographers as the Inshan Range. It forms a natural divide between North China and Mongolia. Starting from the north-eastern corner of the Ordos massif, this range extends eastwards almost continuously for more than 1,000 kilometres until it reaches the Jehol district, where it sweeps round towards N.E. and finally merges into the trend of the Great Khingan. R. Pumpelly and Armond David crossed this range more than half a century ago. They recorded few observations as to its structure. It is only in recent years that somewhat detailed observations have been made in different parts along its length by Teilhard de Chardin,[2] C. C. Wang,[3] W. H. Wong, and the writer himself. The western part of the Inshan comprises the Ulashan and Scheiten Ula, being apparently connected with the Arbus Ula on the eastern side and the Ala-shan on the western side of the upper Hwangho. Whether they merge into each other by gradual change of their axial trend or come into an abrupt contact is yet unknown. In the middle part of the Inshan, which is popularly named the Ta-Chin-shan, overfolds, scharnier and repeated thrusts of considerable horizontal displacement are to be observed along the numerous valleys that cut across the axis of the mountain or the axes of the folds. In the southern part of the range nearly all the dominant folds are overturned or even extensively stretched to the north. Overthrusts also point to the same direction.

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[1] Obrutschev, W. A., *op. cit.*, p. 48.

[2] P. Teilhard de Chardin, "On the Geology of the N.W. and S. borders of Ordos," *Bull. Geol. Soc. China*, Vol. III, 1924, pp. 37–40.

[3] Wang, C. C., "Geology of the Ta-Chin-Shan Range," *Bull. Geol. Surv. China*, No. 10, 1928, pp. 1–18.

Apart from recent alluvium and a peat deposit, all the geological formations present in this section of the range are involved in the disturbance. They are the Jurassic coal-bearing series, Triassic shales and sandstones, the Upper Carboniferous or Permo-Carboniferous coal-bearing series, and lastly the Wutai series, which latter is probably of pre-Torridonian age but younger than the Lewisian Gneiss, as compared with British stratigraphy. None of these rocks are of marine origin. The Wutai is here sometimes metamorphosed to such an extent that it is difficult to differentiate from the Taishan or Fundamental Complex.

The Jurassic together with narrow strips of the Palaeozoic coal-bearing series here and there clinging to its margin, forms a narrow belt in the axial zone of the range. The Wutai rocks are often seen to be thrust over the Jurassic, which is itself overturned to the north on its southern margin. Very remarkable is the fact that in this highly compressed narrow zone, the Jurassic shows little sign of disturbance as soon as we depart from its border of mechanical contact with the Wutai. This cannot be attributed to the resistance of the Jurassic strata, which cannot be more than 900 m. in total thickness. In other words, the resistance offered must be largely traced to the more " competent " base on which the Jurassic rests. This, then, is an excellent example of what Argand calls *charriage cassant.*

Few observations have been made of the contact between the Jurassic and the Wutai on the northern side of the Jurassic belt. Only at one point, some 25 miles to the north of the town of Paotuh, the writer obtained satisfactory evidence that the Wutai rocks are thrust upon the Jurassic, the former being rendered schistose or even mylonized near the plane of thrust. Here, singularly enough, the Wutai is overthrust to the south. Whether this phenomenon is merely local or persists along the entire northern border of the Jurassic belt remains an open question.

Similar types of structure may be traced eastward to the neighbourhood of Kalgan where the land surface is dominated by volcanic plateaus. Thence the structural axes become more complicated, and the region has not been fully explored. Judging from the topography of the country, it appears probable that the range approaching from the west begins, in this volcanic area, to bend towards the north-east as if it attempts to adopt the trend of the Great Khingan, which runs N.N.E. From Kalgan eastward, the country is largely traversed by north-easterly folds ; but within the limit of the latitudes 40° to 42° N., the general array of mountains, which are largely composed of Sinian strata, now and then trends in the E.–W. direction. This is particularly well shown on the northern border of the Province of Chihli or Hopei as it is now named. Local synclines such as the Kiulungshan Basin in the Western Hills of Peking, also assume, with folded Jurassic strata, an E.–W. axial trend.

In the vicinity of Peipiao, a district approximately in line with the Inshan Range, and situated nearly on the border land between the Province of Jehol and Manchuria, W. H. Wong recently observed Sinian Limestone repeatedly thrust over the Jurassic coal-bearing strata as well as a " Cretaceous " volcanic series. The overthrust mass is usually directed to the north-west, but occasionally to the south.[1] We cannot readily connect these dislocations with those of the Inshan Range. The fact that they occur in the same latitudinal position and were simultaneously brought about is however highly significant.

In South Manchuria we find a rather broad zone of Archaean rocks, extending from Mukden eastward to the neighbourhood of Tunghwa and probably beyond. This zone is approximately located between the latitudes of 41° to 42° N. The Ordovician limestone, which is distributed immediately to the south of this zone, likewise extends in the E.–W. direction. We are as yet uncertain as to the structural relation between these rocks; but there cannot be much doubt that they form a part of an ancient E.–W. range which occupies a position comparable with the Inshan far to the west.

Thus we may conclude that this second latitudinal zone of disturbance in Eastern Asia probably came into existence in some early geological time, and that its western portion, which occupies nearly half of its length, was intensely folded and strongly dislocated in post-Jurassic or post-Cretaceous time.

The *Fourth Zone*, which is perhaps the most impressive among the five zones, constitutes the Tsinling Range. It is on the average located between the latitudes of 33° to 34° N., and forms a natural divide between North and South China. F. v. Richthofen, L. v. Loczy, W. A. Obrutschev, Bailey Willis and E. Blackwelder and H. C. Tan have contributed much to our knowledge of its structure. There is not much doubt that the western part of this mighty range merges into the Nanshan Range coming from the north-west. Its eastern part apparently disappears underneath the Yellow Sea. In reality, however, it is tectonically continued to the Island of Shikoku in Japan.[2]

To the north of this range there is that vast plain of North China composed of shattered blocks and overlaid by a mantle of loess. On the southern side of the same range, waves of folds follow. They at first adhere to the trend of the main range, but as they proceed southward, they usually branch off to a south-westerly direction.

The stratigraphical development along the Tsinling Range is somewhat varied. In its western and central parts, pre-Cambrian, Cambro-Ordovician, Siluro-Devonian, Carboniferous, as well as Rhaetic, Jurassic and perhaps Cretaceous strata are present; but as we trace them eastward to the border-land between Honan and eastern Hupeh, all the Palaeozoic formations together with the Rhaetic disappear, and the Jurassic or questionable Cretaceous is only represented in marginal folds on the northern side of the main range. Its tectonic history, too, cannot be simple; for the strike of the disturbed strata now and then deviates considerably from the axis of the existing mountain—a fact well demonstrated by Willis and Blackwelder in the upper Han Valley.

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[1] Wong, W. H., " Étude tectonique de la région de Peipiao et ses environs," *Bull. Geol. Surv. China*, No. 11, 1928, pp. 1–15.

[2] Yehara, S., " Faunal and Stratigraphical Study of the Sakawa Basin, Shikoku," *Jap. Journ. Geol. and Geogr.*, vol. v, No. 1–2, 1926–7, pp. 1 40, plate v.

The composition and structure of the main range appear however essentially alike, at least for a considerable distance in its western and middle parts. Thus the cross-section given by Richthofen from the Weiho Valley to Hantshungfu[1] and that described by Willis and Blackwelder along a meandering pass,[2] some distance to the east of the route followed by Richthofen, agree in showing that a belt of batholitic granite stretches along the northern flank of the main range, followed southward by a zone of metamorphic schist probably of Wutai age; then by compressed folds of Palaeozoic with perhaps Mesozoic strata as well, which are more or less dynamically metamorphosed and often overthrust or overturned to the south. The degree of metamorphism decreases as we proceed southward. To the immediate south of the main range the strata often stand on end, disclosing the roots of once overturned and probably more or less extensively stretched folds. On these denuded folds now and then rests a gently tilted reddish arkose sandstone, to which Willis and Blackwelder assign a late Mesozoic age.[3]

Two other cases of stratigraphical discordance have been recorded within the domain of the Tsinling folds. The one is a section described by Richthofen in a transverse valley of the Kialingkiang between Tshautien and Kwangyenhsien.[4] Here intensely folded and eroded Silurian strata are overlaid by a thick limestone formation which, by reason of its lithology and by comparison with the general stratigraphical development in the Middle Yangtze area, is now known to be of Permian age. It is thus clear that that part of the Tsinling was involved in some pre-Permian movement, probably a phase of the Hercynian.

The second case is reported by H. C. Tan from the northern slope of the Tapiehshan, the eastern extension of the main Tsinling Range that separates the Province of Honan from eastern Hupeh. According to the same observer, in this part of the Tsinling Range a Jurassic coal-bearing series as well as a "tuff-conglomerate" which is also believed to belong to the Jurassic, unconformably overlie the Wutai Schist. The Jurassic strata are disturbed to the extent that they often stand vertically, whereas the tuff-conglomerate rests upon them with only a gentle dip. Tan [1] therefore draws the conclusion that the Tsinling folding took place "during the middle and late Jurassic time or possibly continued into the Lower Cretaceous". By comparing the development of the tuff-conglomerate throughout Eastern China, W. H. Wong [2] is inclined to believe that the stratigraphical position of this formation should be elevated to Lower Cretaceous. Hence, the date of the folding of the eastern Tsinling must be assigned to the end of the Jurassic period. It may be added that some distance to the south of the district where Tan made his observations, that is, on the southern flank of the eastern Tsinling, the writer has observed nothing but micaceous schists and greywackes, which in the more southern zone occasionally contain a layer of white marble. These rocks are compactly folded, and often thrust, sometimes to the north, sometimes to the south. They generally strike east by south, or east-south-east.

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[1] Richthofen, F., *China*, vol. ii, pp. 576–623, Tafel vii, 1882.

[2] Willis, B., and Blackwelder, E., *Research in China*, vol. i, 1907, pp. 299–317, fig. 62 and atlas.

[3] Willis, B., *loc. cit.*, pp. 316–17.

[4] Richthofen, F., *op. cit.*, pp. 602, 614610.

From the head waters of the River Hwai eastward, the main axis of the Tsinling starts to describe an arc with its convex front facing south. Thus in north-eastern Hupeh the axes trend E.S.E. to E.–W., but thence eastward, they sweep round, in the Province of Anhuei, to a north-easterly direction. The north-easterly course of the lower Yangtze is undoubtedly due to this bending of the tectonic axes.

Traced to the other side of the Yellow Sea, the normal E.–W. trend of this latitudinal zone of disturbance is resumed. In Shikoku, Japan, folds and thrusts of a highly compressed type run across the island in an easterly or E. by N. direction; and they are on the average in latitude 34° N. Cretaceous beds are involved in the folding.

The stratigraphical evidence so far obtained would therefore seem to show that at least part of this latitudinal zone of disturbance in Eastern Asia was subjected to orogenetic movements in the Hercynian, Yenshan (= Cimmerian) and probably Laramide movements. We are however uncertain as to whether it was affected, in some way, by movements earlier than the Hercynian or later than the Laramide. There is nevertheless little doubt that a range more or less similar to the present Tsinling was already in existence in early Palaeozoic time; for the Middle Ordovician faunas distributed to the north and south of this zone were already distinct from each other. The northern is characterized by an *Actinoceras* fauna of the North American type; whereas the southern fauna is closely related to the *Orthoceras* fauna of the Baltic Province. Nowhere in China have these faunas been found to occur side by side.

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[1] Tan, H. C., "Mesozoic Formations in S.E. Honan, etc.," *Bull. Geol. Soc. China*, vol. iv, 1925, pp. 251–3.

[2] Wong, W. H., "Crustal Movement and Igneous Activities in Eastern China," *Bull. Geol. Soc. China*, vol. iv, No. 1, 1927, p. 13.

The *Fifth Zone* is the least prominent and also least known of the five. It constitutes the watershed between the Yangtze Valley on the north and the Sikiang Valley on the south, and is approximately situated in between the latitudes of 25° and 26° N. The whole range is known as the Nanling Range. The western part of this range forms the boundary between the Provinces of Honan and Kwangsi; and its eastern part stands as a natural divide between the Province of Kwantung on the south and Honan and Kiangsi on the north. We do not know if the tectonic axes of the western part of this range agree with the axis of the mountain; but we know now that they do agree for some length in its eastern portion.

In a preliminary report yet unpublished, K. L. Fong and H. S. Chu mention a broad zone of granite which extends from Jenhwa eastward to the district of Nanhsiung for about 70 miles or more. In the Meiling which forms the northern frontier of the Province of Kwangtung and rises abruptly above the Nanan Plain on the north, a Meiling Formation consisting of shales, slates, phyllites, etc., is reported to have come into contact with the granite and to be metamorphosed by it. At Meikwang, an ancient fortress on the Meiling, the metamorphosed strata of the Meiling Formation stand on their ends. Southward, these strata gradually change their dip from 70° or 80° to 30° or 40° with a persistent dip to the south. To the immediate south of the Meiling, a Carboniferous limestone makes its appearance again, dipping southward at 30° to 40°. This is in turn covered by the Meiling and a still younger formation with a similar southerly dip.

Somewhat doubtfully, Fong and Chu assume two "faults" which throw the Nanan Plain down against the Meiling Mountain on the north, and against the Carboniferous together with its overlying strata on the south. After scrutinizing the preliminary report, the writer is however inclined to believe that at least the southern fault is really a thrust which brings the Carboniferous upon the Meiling Formation. In another part of the report, the same observers compare the upper part of the Meiling Formation, or the Hwangkang Series, with the Tolo Channel Formation of Liassic age. If this correlation be confirmed, then the date of the Nanling folding could not be earlier than Upper Jurassic.

Eastward, the axis of the Nanling Range apparently describes an arc after the fashion of the eastern Tsinling which likewise bends southward to form an arc. Here, however, the arc is developed on a much smaller scale.

(To be continued.)

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REVIEWS.

The Evidence of the Kimberlite Pipes on the Constitution of the Outer Part of the Earth. By P. A. Wagner. South African Journal of Science, vol. xxv, 1928, pp. 127–48.

THE main thesis of this interesting and important paper is that the innumerable xenoliths of the kimberlite pipes afford samples of the rocks composing the crust in South Africa down to a depth of at least 60 km. They include amphibolites of various types: gabbro, pyroxene-granulite, eclogites of two types, and a great variety of peridotites. The deepest workings of the Kimberley Mine show that amphibolites are beginning there to be conspicuous in the lower part of the granite in the wall rock, and the other rocks are presumed to occur in the order just given, which is that of increasing density. The kimberlite matrix itself is believed to have originated at or below 60 km.

The most noteworthy point is that throughout the whole of the kimberlite pipes, which are known to occur over an area of a million square miles, there are no xenolithic representatives of the presumed glassy basalt substratum, which has been postulated by several writers. It is therefore concluded that in South Africa, at any rate, such a substratum does not exist. It is impossible here to set out the arguments in full: they are founded mainly on the densities and radium content of the different rock types, and appear very convincing. It may be noted, however, that here, as in so many other writings on similar subjects, insufficient attention is paid to Bowen's important generalization, that the partial fusion of a crystalline rock does not in general give rise to a liquid of the same bulk composition. It may be noted that there are a few serious misprints. The following are quoted from a personal letter from the author. On the last line of p. 140, " below " should read " above ", and in the sixth line from the bottom of p. 146, the words " in the form of basalt or basaltic glass " should be deleted. Also on p. 133: " Belastung " should be " Entlastung ".

R. H. R.

Earth Flexures. By H. G. Busk. pp. 1–104, 92 text-figures. Cambridge University Press, 1929. 12*s*. 6*d*.

THIS is the most suggestive book dealing with this aspect of tectonic geology that has appeared for many a long day; it is not only very illuminating to have folds treated from the geometrical standpoint, but it is greatly to the credit of the author that he has done so without the use of advanced mathematics, by the utilization of graphic methods. Whilst mainly written with a view to drawing attention to the need for most accurate section drawing in the problem of oil finding, there is much that is of interest and importance to the general student of geology.

The first two chapters are more or less introductory to the main subject, but contain some useful information, such as the more precise definition of certain terms in common use in tectonic geology and the necessity of distinguishing between the *apex* and the *crest* of an anticline; whether the terms "anticlinal bend" and "synclinal bend" will meet with general acceptance is doubtful, since they can hardly be said to be used in either the "anticlinal sense" or the "synclinal sense" when the dips are in the *same* direction on both limbs of the fold; there is a suggestion that the stress operating in such cases may have been gravitational rather than tangential, and that the fold is of the monoclinal order. In the third chapter the author elaborates his main thesis, and deals with the geometrical construction of earth flexures; this whole section is admirable in its lucidity of exposition, and obviously of considerable importance. The author shows that by graphic methods it is easy to represent earth flexures by a number of tangential circular arcs with normals to the known dips as radii, and hence it is possible to find the curvature of beds that must be encountered below ground with varying dips at the surface; he also shows how a correct estimate of the thickness of the beds involved may be obtained. The various cases are illustrated by a series of propositions of increasing complexity, until from the evidence of a number of surface dips it is possible to construct a complete anticline and syncline, and even overturned folds. In the next chapter he deals with the "axial plane", a familiar but erroneous term for a structure which is really a surface, that may be defined by a number of tangential conics. The understanding of the nature of this structure and its correct location is obviously of the greatest importance in oil work, and Busk has shown most convincingly the results of incorrect location due to insufficient mapping and the absence of sufficient dip controls.

These two chapters are the most important in the book, though the concluding chapters in which he deals with the actual structures met with in some petroliferous areas outside Europe are full of interest not only to the oil-geologist, by whom they should be most carefully studied, but to all students and others interested in tectonic geology. Three areas are dealt with: (1) Burma, where the stratigraphy is straightforward and the structures mainly sharp anticlines and broad synclines; (2) South-west Persia, an area of complex structures in a large measure induced by the unequal resistance of different rocks to earth stresses, and where the effect of denudation by exposing the gypsum horizon in the anticlines has allowed overfolding and thrusting of these pliant rocks over rocks of newer age in the synclinal limbs, sometimes in one direction (Gamma structure), at others in two opposed directions (Omega structure). The sections and block diagrams are for the most part clear and well executed, but some of the maps (Figs. 66, 86, and 88) are hard to make out, and are worth better reproduction.

Altogether, the book gives a clear exposition of a fascinating subject, and should most certainly be carefully studied by all students of oil geology and all those interested in tectonic problems.

The Cambridge University Press is certainly to be congratulated on this addition to their Geological Series.

G. L. E.

THE SUDBURY NICKEL INTRUSIVE. By A. P. COLEMAN, E. S. MOORE, and T. L. WALKER. Reprinted from the University of Toronto Geological Series, No. 28, pp. 54, with 2 plates and a map. Univerity of Toronto Press, 1929.

THE nickel-copper deposits of Sudbury have in recent years given rise to ar acute controversy as to their mode of origin, and the literature of the subject is now very large. The present contribution must be regarded as of first-class importance, since it represents the considered judgment, after a careful re-examination of the ground, of three surviving members of the band of pioneers who originally mapped the district and first propounded the theory of a direct magmatic origin of the ores. Their conclusions are fortified by much detailed petrographic work, as well as by a great number of new and careful chemical analyses of specimens collected during four complete traverses. As the result of all this work, the authors see no reason to modify their original ideas in any essential particular, and it must be confessed that their arguments seem completely convincing. The matter is so important from the point of view of pure petrology as well as of the scientific study of ore-genesis that no apology is offered for reproducing their summary in a slightly condensed form, as follows:—

The eruptive sheet is a unit formed by the segregation of a magma into a more basic portion, norite, passing without a break upwards into a more acid phase, micropegmatite. There is a tendency to the formation of chilled marginal facies, both above and below, nearer to the average composition. In the lowest parts of the sheet sulphides occur as blebs scattered through the norite in such a way that they must have been present when the magma crystallized. In marginal mines the ore passes gradually into pyrrhotite-norite, and the upper limit of workable ore can be determined only by assay. The rock enclosing blebs of ore is perfectly fresh and there is no sign of alteration since crystallization.

There is a marked relation between the width of the intrusion and the size of the ore-bodies, narrow parts and inward bends of the norite edge having no ore, while outward bends at broad parts provide large ore-bodies. While norite always accompanies the ore, other country rocks, granite, gneiss, greenstone, graywacke, or quartzite, do not influence it in any way; the ore is always precisely the same. In unfaulted marginal deposits there is no sign of rearrangement of minerals, but in "offset" ore-bodies (i.e. those lying outside the norite) there are indications of hydrothermal effects. No one denies that the offset ore-bodies have been modified by hydrothermal solutions, doubtless emanating from the magma, but such solutions cannot in any way account for the vast masses of sulphides found in perfectly fresh norite, such sulphides disseminated through the lower part of the basic rock probably far exceeding in bulk the actual separated ore-bodies. "The only possible source of the great ore deposits which encircle the norite-micropegmatite basin is the eruptive mass itself."

In this connection it may be noted that few or none of the authors who have written on this subject have taken into account the importance of the fact that, as shown abundantly by Vogt, the freezing point of sulphides is far lower than that of the common rock forming silicates. As this is the case, sulphides must as a rule be late constituents of the rock and moulded on the earlier-formed minerals. Neglect of this simple fact, as pointed out by Dr. Wagner, has led to much confused thinking by petrologists. The conception of a still liquid sulphide phase *below* an already solidified silicate phase will account for many obscure petrological phenomena, especially if the whole mass is subjected to earth-squeezing even of a minor type (offset bodies), while magmatic hydrothermal residual solutions in addition may greatly confuse the issue.

It is to be hoped that this masterly presentment of the case may once for all settle this question, which is of fundamental importance in theories of ore-genesis.

R. H. R.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

11*th June*, 1929.

Mr. E. J. Wayland and Dr. L. J. Spencer: "Bismutotantalite, a New Mineral from Uganda."

This was found in a pegmatite vein at Gamba Hill, about 35 miles north-west of Entebbe. The large rough crystals, weighing up to a kilogram or more, are orthorhombic, with a habit and axial ratios similar to those of columbite. Analyses made by Mr. W. O. R. Wynn at the Imperial Institute give the formula $Bi_2O_3.Ta_2O_5$, analogous to stibiotantalite, $Sb_2O_3.Ta_2O_5$.

Dr. L. Hawkes: "On a Partially-fused Quartz-Felspar Rock and on Glomero-granular Texture."

In a partially melted granite fusion began at the quartz-felspar contacts. It is suggested that the temperature was raised above the eutectic point but not to the melting point of any of the constituent minerals, and that a granite of quartz-orthoclase-albite eutectic composition will melt completely in the dry state below 950° C. Coarse-grained granites may exhibit a segregation of quartz and felspar, revealed in section by monomineralic areas of several grains in anhedral intergrowth. The name "glomero-granular" is proposed for this texture, which may result from the normal undisturbed crystallization of the magma.

Dr. P. Marshall: "The Occurrence of a Mineral Hitherto Unrecognized in the Phonolites of Dunedin, New Zealand."

A mineral with low birefringence and low refractive index hitherto taken to be either nepheline or sodalite is shown to be distinct from these and to be nearer microsommite or davyne. It is usually allotriomorphic, but also occurs as very small (0·15 mm.) hexagonal prisms. Analyses of HCl-solution of phonolites containing this mineral to the exclusion of other soluble silicates indicate that it is a sodium alumino-silicate loosely combined with sodium chloride. The mineral stains dark violet when treated with silver nitrate. The name proposed for the mineral is ameletite.

Dr. G. T. Prior: "The Meteoric Stone of Lake Brown, Western Australia."

The stone, weighing when found 4·75 kg., has been known since 1919. Chemical analysis and microscopic examination prove it to be an intermediate hypersthene-chondrite of Baroti type.

Mr. I. de Finály and Dr. Sándor Koch: "Fülöppite, a new Hungarian Mineral of the Plagionite-semseyite Group."

This was found at Nagybánya, Hungary [= Baia Mare, Romania], as small monoclinic crystals of the plagionite habit. Analysis shows it to be an acid member of the group with the formula $2PbS.3Sb_2S_3$. Associated with it is an acicular (probably orthorhombic) lead-antimony mineral with the composition $3PbS.4Sb_2S_3$, which is compared with the Bolivian keeleyite.

OBITUARY.

Sydney Savory Buckman.

BORN 3RD APRIL, 1860. DIED 26TH FEBRUARY, 1929.

Sydney Savory Buckman was born at Cirencester, where his father, James Buckman, was then Professor of Geology and Botany. Most of his early life, however, was passed at Bradford Abbas in Dorset, in the midst of some of the richest fossil-bearing rocks in the world. He naturally became a keen fossil-collector, and as early as 1878 published his first paper on the Inferior Oolite Astartes. He soon concentrated on Ammonites and Brachiopods, and his first paper on the former group appeared in the same volume of the *Quarterly Journal* as his father's last; the difference in outlook of the two drew immediate comment, for while James Buckman reported species of different zones from the same bed, his son was already a follower of William Smith and Oppel, and convinced that apparent discrepancies in zonal distribution were due either to bad palaeontology or inaccurate stratigraphy. At the suggestion of Thomas Davidson, he undertook the preparation for the Palaeontographical Society of a monograph on the Inferior Oolite Ammonites, the first volume of which came out at intervals from 1887 to 1907, during which time the author's ideas developed so extensively that the later instalments of the work were largely corrections of the earlier. The Palaeontographical Society would not agree to the publication of a second volume, and Buckman thereupon started a publication of his own, at first somewhat on the lines of the *Palaeontologia Universalis*, originally *Yorkshire Type Ammonites:* this broadened into *Type Ammonites*, and had reached in twenty years its seventh volume and almost the eight hundredth species when his final breakdown in health occurred last summer.

Parallel with his steady output of papers on Ammonites, there was an almost equal flow on Brachiopods, and a series of contributions on Jurassic stratigraphy. The detailed study of ammonite and brachiopod zones led to the realization of intra-Jurassic earth-movements and erosions, which gave fresh evidence for Godwin-Austen's principle of continuity of folding. Buckman was always ready to apply the idea of evolution to any subject, and, besides some contributions to Anthropology, he contributed in 1899 to *Natural Science* an application of W. M. Davis's principles of river-evolution to English rivers, which has hardly received the attention it deserves.

Buckman married, in 1882, the daughter of the botanist whose romantic association with his father is mentioned in *Type Ammonites* (v, 26), to whom he had already dedicated a terebratulid (now *Heimia hollandae*) and who with four sons and four daughters survives him. Kind of heart and with a keen sense of humour, ever ready to help his fellow-workers, his memory will be cherished by those who knew him. The value of his contribution to science is difficult to realize, for so much of it has been absorbed into contemporary thought that the unaccepted fragments appear unduly prominent to the younger generation.

A. M. D.

CORRESPONDENCE.

AFRICAN RIFT VALLEYS.

SIR,—In a paper entitled " The Origin of the Great Rift Valleys as evidenced by the Geology of Coastal Kenya ", *Trans. Geol. Soc. S. Africa*, vol. xxi, 1928, pp. 63–96, Dr. E. Parsons—who has done a great deal of valuable work in Eastern Africa—set forth certain conclusions, the correctness of which has recently been disputed by Mr. Maufe and Professor J. W. Gregory. My own silence in respect of this matter is, I gather, likely to be taken as indicative of concurrence with Dr. Parsons' views, and I am anxious to dispel that impression.

Those who are interested in the matter, and many geologists are likely to be so in view of the impending meetings of both the International Geological Congress and the British Association in South Africa this year, would do well to consult *Min. Proc. Geol. Soc. S. Africa*, 1929, pp. xliii–vi (proof subject to alteration just issued).

Dr. Parsons' views concerning the existence of thrusts at the coast may be right or wrong, but to one no better acquainted with the geology of that part of Kenya than I am they are unconvincing; and (although I am not one of those who accept the tension theory) I do not think they bear of necessity on the origin of Rift Valleys; for it is not proved that the forces that gave rise to these structures originated outside (to the east of in this case) the continent.

My own attitude towards the interpretation of Rift Valleys will be explained at a meeting of the International Geological Congress in Johannesburg, where I am to have the privilege of opening a discussion on that subject. Meanwhile, however, I should like to say that although the movements that gave rise to the Rift Valleys may be but a repetition of similar activities that have manifested themselves more than once in the geological history of enormous areas of Africa, there can be no doubt that Maufe is right when he suggests that the folding of the Karagwe-Ankolean beds of Uganda and Tanganyika Territory occurred in a period long prior to that in which the present Rifts appeared. Not only so, but the folding of the Karroo, which is later than that of the Karagwe-Ankolean, also belongs to geological antiquity; for the Karroo basins, no less than older structures, were surface-levelled by a vast peneplain which had reached an advanced stage of maturity before the occurrence of certain warpings and the Rift Valleys associated with them.

E. J. WAYLAND.

15 WESTCLIFF TERRACE MANSIONS,
RAMSGATE.
19*th May*, 1929.

THE CHERTS OF NORTH FLINTSHIRE.

SIR,—Dr. G. M. Lees has given us an interesting paper on "The Chert Beds of Palestine",[1] but his summary in that paper of the massive chert-formation of North Flintshire contains inaccuracies which cannot be allowed to pass unchallenged.

(1) There is no massive chert at or near Colomendy. That locality is far removed from the chert-outcrop.

(2) The development of the chert is widespread and not "local", and the numerous exposures ranging from 20 or 30 up to nearly 100 feet in thickness are certainly not "poor".

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[1] *Proc. Geol. Assoc.*, xxxix, 1928, pp. 445–62.

(3) Dr. Lees states that intraformational folding and brecciation of the chert have resulted from physical changes subsequent to deposition, leading to increase of volume.

The only intraformational folding consists of small local synclines and quâ-quâ-versal folds which have been adequately described and explained by Strahan, as follows: "The lower beds of the chert frequently *in this district* dip at high angles in abnormal directions, although their boundary preserves its normal strike. A good instance occurs by the side of the road to Halkin Hall, and a quarry on the south side of the road provides the explanation, for the strata dip here from all sides at steep angles towards the centre of the pit in such a way as to show that the rock beneath has given way, probably owing to the collapsing of a cave in the limestone."[1]

Dr. Lees quotes only the first sentence of the foregoing description, and he omits the three words I have italicized, which are of obvious significance. There is no evidence of a subsequent change of volume such as he postulates, and his theory of an "internal expansive force" is needless, as well as incompetent, to explain the intraformational folding or the brecciation of these cherts.

(4) The chert is not "completely devoid of any organic structures". Thin sections show sponge spicules and other organic structures. Crinoids and corals, though very scarce, are sometimes seen.

I regret the necessity of having to point out these inaccuracies in Dr. Lees' summary of the Flintshire Cherts.

H. C. SARGENT.

THE NOMENCLATURE OF FOLD-SYSTEMS.

SIR,—In response to your suggestion for further views on general names for fold mountain systems, I beg to support Professor Boswell's suggestion for the adoption of -id. I recommend its application to Altaids, which I used in the *Geographical Journal*, June, 1915, for example p. 501.

J. W. GREGORY.

THE UNIVERSITY, GLASGOW.
10*th May*, 1929.

[The pronunciation of such a form as Africids also needs consideration. The variations of the letter *c* in English are a constant source of trouble in words of this kind. Is it to be *Afrikids* or *Afrisids* ?—ED.]

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[1] "The Geology of the Neighbourhood of Flint, Mold, and Ruthin," *Mem. Geol. Surv.*, 1890, p. 50.